Instruments

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INCLUDING

Aviation Instruments

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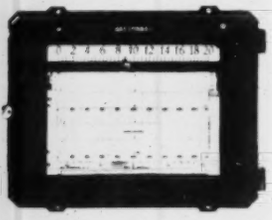

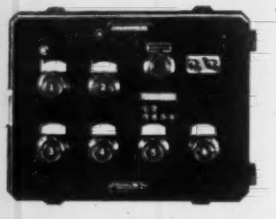

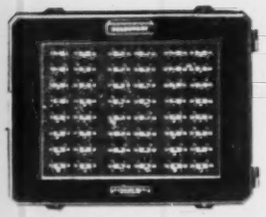

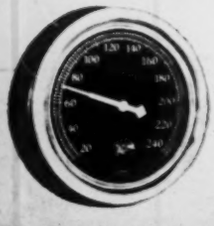

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Nearly half a century of service to Industry recommends TAG Indicating, Recording and Controlling Instruments for Temperature, Pressure, Time, Level and Flow.

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C. J. TAGLIABUE MFG. CO.

Park and Nostrand Aves.
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Instruments THE MAGAZINE OF Measurement and Control

M. F. BEHAR, Editor

This month's front cover shows women inspecting instrument jewels—a work they do better than men. Women in war industries, however, don't solve the real problem.

MAN-POWER now looms as Problem No. 1. Stimson predicts an army of 7,500,000 by the end of '43. Experts warn that every soldier and sailor must be backed by fifteen to nineteen industrial workers—the rate depending on the statistical-survey method (and perhaps on the surveyor).

Even the 15:1 ratio means more than 110,000,000 workers. The total civilian population of working age (15 to 70) is roughly eighty million. Some twenty million have to remain in essential non-war occupations. Other millions are unfit. War industries cannot count on much more than fifty million (ages 15 to 70, both sexes).

The ratio can no longer be 19:1 or 15:1. It MUST be brought down to 9:1, yes, even to 5:1. How? by extending American labor-saving genius into fields where manual and visual methods are still used. *Instruments* has been pointing out for years that Inspection and Gaging is the most promising field. Read this page *and* page 397.—MFB

Jan. '34

BITTER controversies rage over "technological unemployment." The persistence of this term in the vocabulary of non-technical politicians, writers and broadcasters betrays muddled thinking—if not ignorance of the industrial basis of a decent civilization. Unfortunately, the clear-headed majority among our [illegible] industries. *Instruments* will keep on fostering the march of automaticity as long as it endures. And to show we mean what we say, we shall use a portion of this very editorial to help widen the scope of Instrumentation by deliberately promoting its extension into the field of *inspection operations.*

To be sure, this has for years been one of our objects, but on December 13 we had the thrill of seeing an instrument (rather, a machine comprising five distinct instruments) which is used by the Ford Motor Company to inspect and classify engine wrist-pins.

Ground case-hardened pins enter one end of the machine at the rate of 38 a minute and are conveyed along its length past five stations spaced 7½" apart, halting at each station for a particular inspection (like "physical exam day" in the Army.) Station 1 tests automatically for surface smoothness by means of a Carboloy-tipped feeler swung in the field of a magnet in such manner that when roughness causes deflection beyond permissible extent, an amplified current trips a relay and the pin is ejected. Station 2 tests for scleroscopic hardness; if the hammer rebounds less than the proper extent between a light source and a photocell, a relay is tripped and the pin ejected. Station 3 tests for cylindricality by means of a U-shaped feeler which a taper of 0.0003" causes to deflect sufficiently to actuate a relay. In a somewhat similar manner Station 4 tests for concentricity by the three-point method. Station 5 measures diameter and its pointer controls a chute leading to one of five bins: oversize rejects, + 0.0001", ± 0.00005", — 0.0001", and undersize rejects.

We urge all industries now relying on manual and visual methods for such inspections to install automatic instruments similar to any or all of the five "stations" described above, thereby decreasing the sum total of human toil and increasing the per capita leisure of the American people.

Whatever device diminishes the sum total of drudgery—of repetitive labor tending to sharpen one faculty at the expense of all others—is a blessing. Don't use fewer such devices, as some politicians advocate; use more of them!

Don't let those politicians delude you into thinking that prices of [illegible] civilization [illegible] earners. We repeat: don't use fewer instruments designed to cut down the labor content of your products; install *more* of them to expand your business and give work to more men [illegible] and "produced-not purchased." We Americans can increase leisure by living like savages who don't travel, don't buy "gadgets," don't read, write or 'phone and therefore have no industries; but to increase both leisure and industrial activity we must adopt more and more leisure-producing instruments and control devices.—M. F. BEHAR

Nov. '34

"100% Automatic Inspection"

FROM time to time we are asked, "what is the most promising field of Instrumentation today?" In the inquirer's mind, of course, the question may be, "In what branch of Instrumentation am I likely, at this time, to find the best opportunities?"

On this subject one man's opinion is—one man's opinion. While we never refuse to answer, we prefer to analyze individual cases, for our opinion in *general* terms is that *all* fields of Instrumentation are "promising."

We should like to hear the question put with one word changed, thus: "What is the most promising field FOR Instrumentation today?"

To such a question we are prepared to snap a two-word answer, to shout with fanatical passion the magic words "Automatic Inspection."

Skeptics will say that this is a field where human judgment reigns supreme; that even where limit gages and comparators are used they must be handled by trained inspectors; that the most important kinds of inspection are *tests* which can never be automatized; that no robot can be built for automatically judging "quality" or passing on "properties"; that even if automatic inspection instruments have been built, they can't amount to much and that those in use are outnumbered a million to one by the "regular" types of indicators, recorders, meters and controllers—by the familiar forms of measurement and control devices, by the myriad examples of "logical" or "common-sense" Instrumentation.

We are confident that our subscribers will not only refuse to join the scoffers but will discover many opportunities in this *uncultivated* field—and will appreciate the richness of the rewards in store for diligent cultivators.

Seldom was the trite expression "barely scratched" more applicable. As the skeptics say, the ratio of automatic regulators to automatic inspectors (*in use*) is a million to one. But while their inference is "it won't work," our conclusion—and yours—is "It Can Be Done!" As evidence we adduce the automatic inspectors and "property controls" which *have* been fully developed: Few in number, to be sure, but significant as pieces of evidence.

One example: Just four years ago—in the November 1930 issue—sermonizing on the scientific instrument of today being the plant instrument of tomorrow, and discussing the vanishing line between laboratory testing devices and industrial production instruments, we wrote

> Today there are no industrial instruments pertaining to hardness. Tomorrow one may be invented and in a few years we may witness the production of bar stock whose hardness is controlled not in the laboratory but automatically during production.

Now, in 1934, this very thing is being done in a razor blade factory: as the high-carbon strip passes out of a continuous furnace, its hardness is measured by an automatic inspector that never tires, never stops for a drink, never stares at the girls but incessantly carries out the orders which the human inspector gives it from time to time. This robot not only inspects every inch of the fast-moving strip but it controls the furnace with superhuman alertness so that every inch of strip has just the right hardness.

This, of course, is such a marvel of Instrumentation that cynics may dismiss it as a "curiosity," but the fact remains that the gap between (in this case) magnetic *testing* in the laboratory and magnetic *inspection* in the plant has been bridged. Of greater significance is that the problem of rejects and seconds has thereby been solved: instead of subsequent human "guesstimation" as to which lots of blades are good and which are bad with respect to the property known as "hardness," the robot inspector sees to it that the continuous furnace turns out nothing but good strip.

Our enthusiasm, however, is not based on curiosities but on the increasing number of successful automatic inspectors already on the market. Look over our New Instruments Section beginning with the 1931 or 1932 issues and observe the trend for yourself. M. F. BEHAR

Put Idle Instruments to Work!

The Instrument Publishing Co.'s Plan

Revised Text Submitted to WPB

UNPRECEDENTED demand for measuring and testing instruments, automatic controllers, control valves, laboratory instruments and apparatus, etc., together with extreme shortages of materials used in their manufacture, have created a situation calling for some plan to be evolved for a more complete utilization of all available equipment.

Instruments, controls, inspection equipments, etc., are frequently engineered to exact specification for each application, but it is felt that some processes and laboratories now relatively idle have instruments that might be utilized.

It often happens that the shortage of materials causes a delay in the delivery of new instruments, controls, etc., to such an extent that considerable time could be saved through the adaptation of a "used" instrument, valve, etc.

With the endorsement of the Instrument Section of the General Industrial Equipment Branch of the War Production Board, the Instruments Publishing Company hereby offers its office as a means of exchange of information between those that "have" and that "want."

Owners of idle instruments and devices for measurement, inspection, testing and control should make them available for sale so that they can be placed in plants engaged in war production, in laboratories, etc.

Full information regarding such idle instruments can be forwarded to the **Available Instruments Department, Instruments Publishing Company, 1117 Wolfendale St., Pittsburgh, Pa.,** where it will be incorporated in files for use by operators of war production plants.

To make the records uniform, sheets 8½" × 11" should be used, listing one instrument or device on each sheet. A copy of each record should be retained until the item is sold, then the owner's copy should be forwarded to the Available Instruments Department of the Instruments Publishing Company, marking "SOLD" across its face.

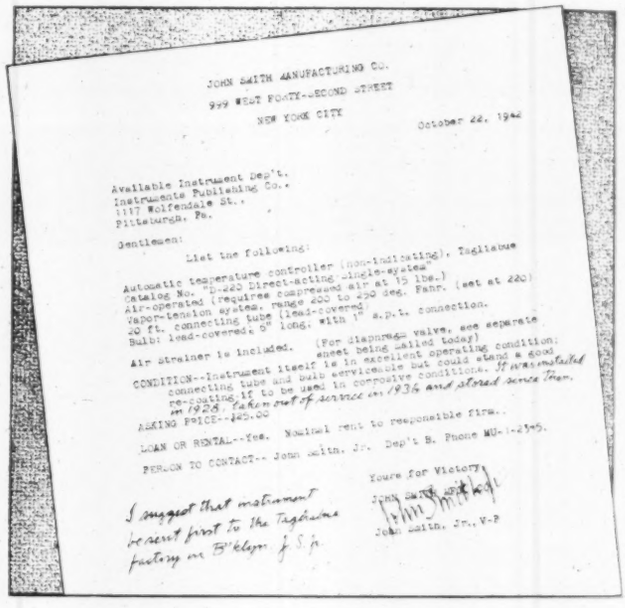
In listing available instruments for sale, give name of original manufacturer, type, range and description including age, catalog number, serial number and condition of instrument, also cases and auxiliaries when these "go with" the instrument proper and are available.

The name of the owner, the asking price, the name and address and telephone number of the person to contact for purchase should also be included.

If the instrument is not available for sale but can be obtained on a **loan and rental basis,** please so state.

The Instruments Publishing Company will be glad to put inquirers in appropriate contact with those who can supply their needs. In so doing, the Company assumes no responsibility and owners of instruments must make their own arrangements with prospective users.

The use of this equipment "as is" will be another test of the "Yankee ingenuity" for which this nation is credited, and will add a spoke in the wheel on which our country is driving toward Victory.



JOHN SMITH MANUFACTURING CO.
999 WEST FORTY--SECOND STREET
NEW YORK CITY

October 22, 1942

Available Instrument Dep't.
Instruments Publishing Co.
1117 Wolfendale St.
Pittsburgh, Pa.

Gentlemen:

Automatic temperature controller (non-indicating), Tagliabue Catalog No. "D-460 Direct-acting single-system" Air-operated (requires compressed air at 15 lbs.) Vapor-tension system, range 400 to 490 deg. Fahr. (set at 220) 20 ft. connecting tube (lead-covered) Bulb: lead-covered, 9" long, with 1" s.p.t. connection.

Air strainer is included. (For diaphragm valve, see separate sheet being mailed today)

CONDITION--Instrument itself is in excellent operating condition: connecting tube and bulb serviceable but could stand a good re-coating if to be used in corrosive condition. *It was installed in 1928, taken out of service in 1936 and stored since then.*

ASKING PRICE--$45.00

LOAN OR RENTAL--Yes. Nominal rent to responsible firm.

PERSON TO CONTACT-- John Smith, Jr. Dept B. Phone MU-1-2345.

Yours for Victory,
John Smith
John Smith, Jr., V-P

I suggest that instrument be sent first to the Tagliabue factory on Bklyn. L.I.

This is a mere suggestion, not a form to be followed exactly. Do not forget to keep a copy and to send it to the Available Instruments Dep't, marked "SOLD," when the instrument is sold.

Instrument Publishing Co.'s Plan Approved by Instrument Section of WPB

WAR PRODUCTION BOARD
WASHINGTON, D. C.

September 11, 1942

The Instruments Publishing Co., Inc.
1117 Wolfendale St.,
Pittsburgh, Pa.

Attention: Mr. Richard Rimbach, President.

Gentlemen:

The proposed plan to make available idle industrial instruments, regulators, control valves, etc., has been reviewed and discussed.

The members of the Industrial Instrument Advisory Committee expressed their separate approval of this plan and it can be expected their cooperation will be received in its execution.

The plan is certainly a step in the right direction and is therefore endorsed by this Section.

These transactions of second-hand industrial equipment in the form as is, can be made without the need for priority assistance and also are not restricted by the terms of Conservation Order L-134.

This plan appears to have considerable merit and it is hoped it will be possible to start it in operation promptly. In this you have our wish for success.

Very truly yours,

C. S. WILLIAMS, *Chief*
General Industrial Equipment Branch
By: ERNEST A. CAPELLE, Chief,
Industrial Instrument Section

Calling All Readers with Ideas on Speeding War Work

(even old ideas—*especially* old ideas now producing results that should be better known)

IF you love America—and of course you do—it is your duty to do all you can to help America's mighty war industry grow mightier . . . fast! True, you are already going all out on your own job: at every month's end, you know you've done a good month's work to axe the Axis. (You've probably done what was two months' work before Pearl Harbor!) But perhaps you can make a suggestion that will save thousands of work-months. Yes, you, the typical reader: most useful suggestions don't come from a few geniuses but from the many wide-awake workers—each alert to see some "tremendous trifle" that had previously escaped notice. Especially is this true now. Especially is this true with regard to the use of instruments. And that's where you shine! One big bottleneck is that millions of inspectors and testers still have to rely on their hands, their eyes, their judgment subject to fatigue. Yes, here in America, where automatic gadgets have been invented, each doing the work of twenty or two hundred humans and doing it better! The pity of it is that there is no need for this bottleneck—because every type of test or determination is being done automatically somewhere. The few basic inventions have all been made; what's needed is ten thousand adaptations or applications—such as you have in mind right now . . . or such as you have already installed. (Don't be too modest: that "unimportant" automatic method over in the corner of the second floor of Building R-73 may not have been brought to the attention of the thousands who should know about it.) And there are some other bottlenecks in production that can be eliminated by the use of automatic instruments.

NOTE—In lots of places the inspectors and the management are so proud of "doing it in half the former time" that they can't imagine any further improvement *(but it could be done in one-hundredth the former time)*. In some cases there is a belief that the Army or Navy "wants it done just that way" *(but the spirit of A&N specs is results, not methods, and the higher officers want faster methods—provided that quality is not impaired but bettered)*. In many instances the only ban on automaticity is that the product to be tested or measured or controlled automatically or continuously is "different" *(but the instrumental function to be performed is exactly the same!)*.

YOU ARE INVITED, therefore, to send in your suggestion (or suggestions) for publication in the big January Special Issue of *Instruments*. The rules are simple:

1. Everyone is invited.

(On some previous occasions we excluded persons in the employ of instrument companies. Not this time! If you have worked out a new labor-saving application of any device, don't hold back because you happen to be selling that device. If one of your customers has worked it out, have him write it up; and if he is too busy or too modest, write it up for him.)

2. Contribution should be typewritten, double-space, on one side of $8\frac{1}{2} \times 11$ (or $8 \times 10\frac{1}{2}$) paper. Name and address of author typed at top of first page; name at top of other pages.

3. Diagrams should be in black ink on white paper (or tracing cloth or paper). No blueprints. Name and address of author on each diagram. *Good* photographs will be accepted.

4. Each contribution to describe the solution of ONE specific problem. Each author, however, may send as many as he wishes.

5. Be brief, but don't omit descriptive details.

(If you describe the continuous automatic measurement of something usually measured intermittently by hand, don't write a book about the theory of automatic continuous measurements. On the other hand, don't send in something like this: "We have an automatic tester for length, weight, hardness and profile of A-P cores that replaces twelve girls." **That** is **too** brief.)

6. A solution need not be an instrument: it can be a fixture, a conveyor, or any set-up that *makes possible or practicable** the use of an automatic instrument.

7. Write it up TODAY then put it away; a few days later, read it with a fresh mind and add any essentials you might have overlooked. All contributions must be on your editor's desk in Pittsburgh by Monday **December 7th.**

8. Owing to the large volume of mail received at this office, it is essential that all articles written in response to this invitation be addressed to: **War Work Speed-up Editor, The Instruments Publishing Co., 1117 Wolfendale St., Pittsburgh, Pa.**

*For years I've been advocating the full-automatic or conveyorized inspection of artillery ammunition but always was told that although it is **possible** it is **impracticable** because moving heavy projectiles (above .50-cal.) wear down fixed gazing anvils or vees in hours or even minutes; because the elaborate hydraulic mechanisms for speedily shifting and then gently lowering the shells would take too many man-years to design, develop and test; and because they would require more man-years to manufacture in adequate ranges of sizes and models than would be saved. I was told that a typical installation would cost $25,000. Well, I'd like to see what **you** can do with shock absorbers now available by the millions in auto graveyards, plus a simple gravity-roll feed; maybe your installation (exclusive of the automatic electric or pneumatic gage and relay for tripping rejects) would cost nearer $25 than $25,000.—M. F. BEHAR, Editor, **Instruments.**

Thermometric Lag Determination for Cylindrical Primary Elements

By M. J. ZUCROW
Research & Development Engineer, Elliott Company, Jeannette, Pa.

Editorial Foreword for Non-mathematical Readers

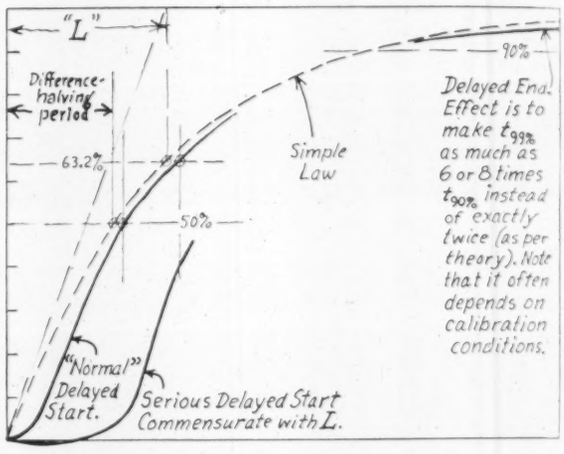
THERMOMETRIC LAG is a common source of serious errors in industrial temperature measurement and control. It is a source of error in measurement because it means that the temperature of the primary element is *never* the same as the temperature of the medium—except momentarily when the curves cross each other. The error is greatest in the case of changing temperatures—the ones which are most important in industrial work. It may be several degrees in thermometry or several dozen degrees in pyrometry. This error may be considerable also in the indication or recording of fairly "steady" temperatures because lag is often due to an undesirable escape of heat in the vicinity of the primary element as well as to an undesirable retardation of heat flow to or from the primary element itself.

Primary-element lag makes close control impossible. For years your editor has summarized the reasons in three slogans:

1. *No controller is better than its primary element.*
2. *The controller is always too late with too little (followed by too much) corrective action.*
3. *Dead times mean dead zones.*

The usual text-book treatment of thermometric lag is based on Newton's Law of Cooling—an over-simplification of what really happens in an industrial installation of a thermometric or pyrometric primary element which is not a single elementary part but a mechanical structure. This complexity of the actual bulb, thermocouple, etc., sometimes with heat-conducting bushings, etc., formerly made it difficult to compute exactly the various components of lag for any particular structure—and even more difficult to predict the total lag of any particular structure. In recent years, however, progress in heat-transfer engineering has removed most mathematical difficulties. Now it is known that industrial temperature-measuring structures are characterized by lag curves in which there is a noticeable "delayed start" and a noticeable "delayed end" (two terms we proposed early in 1941 to clarify thinking and visualize the physical meanings of mathematical expressions). The delayed start and the delayed end refer, of course, to the difference between the lag curve of an actual industrial bulb or thermocouple and the ideal curve of Newton's Law.

At the recent Gibson Island Research Conference of the American Association for the Advancement of Science, two lectures were given, one by Dr. Zucrow on the general subject but containing data on the delayed start; the other, chiefly on the delayed end, by Dr. Bradford Noyes of Taylor Instrument Companies. This occasion was a milestone in *industrial* temperature instrumentation and all persons concerned decided that these two lectures should be published in *Instruments*—not exactly as delivered but rewritten especially for the industrial audience which is served by *Instruments*. It was your editor's intention to print both these articles in one issue of *Instruments*. Unfortunately, ill-health has prevented Dr. Noyes from finishing his article. Since the two articles deal with essentially different subjects, we are printing Dr. Zucrow's article in this month's issue and we join our readers in wishing Dr. Noyes an early return to perfect health.


"L"
Difference-halving period
63.2%
50%
90%
Simple Law
Delayed End. Effect is to make $t_{99\%}$ as much as 6 or 8 times $t_{90\%}$ instead of exactly twice (as per theory). Note that it often depends on calibration conditions.
"Normal" Delayed Start.
Serious Delayed Start Commensurate with L.

Rough visualization. (From an article in *Instruments*, Vol. 14, May 1941, pages 123-136.)

Although Dr. Zucrow's article appears at first glance to be mathematical, it really is a practical guide to the solution of practical problems. His figures, tables and method of analysis make it relatively easy for an industrial instrument man (even a man without mathematical training) to determine whether the delayed start is considerable or trifling in any particular case. Only a few dimensions and other figures have to be known at the start; and it should not take longer than a few minutes to obtain a rough answer—accurate enough to decide whether the installation should be altered.

Even the workers who require exact solutions will find that Dr. Zucrow has provided them with a method that will reduce days of calculations to perhaps not more than half an hour. —M. F. BEHAR

1. INTRODUCTION

IN a distant-reading thermometer system, thermometric lag depends upon the factors governing the transfer of heat to the temperature-sensitive element from the medium having its temperature measured. Lags may also occur in the transmission of temperature changes to the recording, indicating or controlling instrument. These will not be discussed. This should not be taken to imply, however, that transmission and instrument lags are always negligible. Furthermore, a knowledge of the total of all lags for a thermometer system is of considerable value in analyzing either hand-controlled or automatically-controlled processes.

For heat to be transferred to the temperature sensitive-element from its surroundings, or vice versa, a temperature difference must exist between them. This applies to both the steady state and transient conditions. Since the thermal resistance of the temperature-sensitive element is relatively low, when the element is correctly installed this temperature error is usually negligible under steady state conditions. However, unless its installation takes full cognizance of the heat transfer factor involved, surprisingly large errors may be introduced.

In general, the same variables which affect the aforementioned temperature error govern the thermometric lag. They are the dimensions, construction and shape of the temperature-sensitive element, its thermal conductivity, spe-

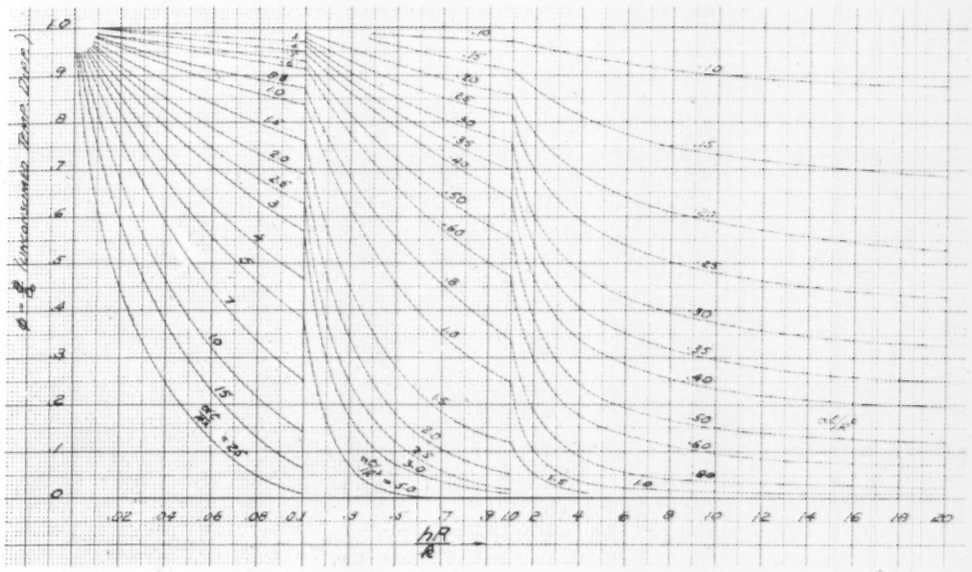


Fig. 1. Temperature change at Axis of Infinitely Long Cylinder in a Heat-transfer Medium. (Schack, S.&U., 1930.)

cific heat, density and the surface heat transfer coefficient. The latter, of course, depends upon the character of the medium having its temperature measured, its Reynolds number and the direction of its flow with respect to the measuring element.

Heat flows from the medium to the axis of the thermometer bulb mainly by the mechanisms of convection and conduction. In some cases radiation also plays a part but in this discussion it is assumed that convection and conduction control the heat transfer process.

In the usual socket-protected measuring element, the heat is first transferred to the exterior surface of the socket by convection and then flows radially inward by conduction through the various heat flow resistances incorporated in the structure. Several different materials are involved, all having different thermal conductivities, specific heats, densities and physical dimensions. Consequently, the calculation of the overall thermal conductivity for the temperature element is frequently rather difficult.

An insight into the effect that different materials or installation conditions may exercise on the rate of heat transfer can be obtained from Table I. The effects of the character and velocity of the fluid on the heat transfer coefficient are illustrated in Table II.

From Tables I and II it is apparent that the magnitude of the thermometric lag depends not only on the overall conductivity of the temperature-sensitive element but also on the installation conditions (including fluid medium velocity, direction, etc.) because these conditions control the surface heat transfer coefficient. Consequently, any comparisons of thermometer response should be based upon identical installation conditions.

The basic problem in a thermometer application is to predict from simple laboratory tests what the response characteristics of the thermometer will be in an actual installation. To obtain information of this character, it is necessary to know or be able to evaluate the heat transfer factors entering into the installation. In most cases the available data are limited. But certain factors are known or can be closely approximated. One does know, however, the dimensions of the temperature sensitive element; and its average density and specific heat can be determined by fairly simple tests. Furthermore, from published data the heat transfer coefficient for the exposed surface in different media can be determined with a fair degree of accuracy. The information usually lacking is the overall thermal conductivity of the temperature-sensitive element and its protecting tube. This can be determined inferentially, however, from simple tests and available heat transfer data in the manner to be discussed.

Table I—Representative Heat Transfer Rates

(W. J. King, *Mechanical Engineering*, March 1932)

Mechanism	Material	Heat Transfer Rate (Btu.ft.$^{-2}$hr.$^{-1}$°F.$^{-1}$)
Conduction	1/16" Copper	12,600
	1" Corkboard	0.30
	1/16" Oil	15.00
	1/4" Air	0.67
Free Convection	Plane Surface in Air	0.60
	Plane Surface in Water	150.0
Forced Convection	Water in pipe line	1200
	Air over tubes	8

2. Effect of Sudden Temperature Change

The problem of heat flow to geometric bodies suddenly exposed to a different temperature has been studied by H. Gröber, A. Schack, A. Newman and others (see Bibliography). The results of these studies make it possible to determine the transient temperature conditions for these bodies: the cylinder, the sphere and the flat plate. The analysis for the temperature history at the axis of cylindrical shapes can be applied to the evaluation of thermometric lag.

Table II—Heat Transfer Coefficient b for Different Fluid Flowing Past Cylinders

(kg. cal. m.$^{-2}$ hr.$^{-1}$ °C.$^{-1}$)

(Fr. Lieneweg, 1937)

Fluid	Velocity 0 — Radius, mm. 2	5	10	2 m/s — Radius, mm. 2	5	10	5 m/s — Radius, mm. 2	5	10	10 m/s — Radius, mm. 2	5	10
Water												
30°C.	720	600	500				1000 to 10,000					
50°C.	1200	980	820									
70°C.	1650	1320	1200									
Air												
50°C.	13.8	9.8	8.8									
100°C.	17.3	12.7	10.9	42	37	33	69	60	55	103	90	80
200°C.	21.8	16.2	14.6									
Steam												
5 atm. 300°C.							90	135	225	110	195	310
20 atm. 400°C.							240	330	530	330	470	740
50 atm. 300°C.							650	950	1550	950	1350	2220
Machine Oil 70°C.	0 — Radius, mm. 2	5	10	0.01 m/s — Radius, mm. 2	5	10	0.1 m/s — Radius, mm. 2	5	10			
	15	31	24	150	100	75	450	290	200			

1 (kg. cal.)/(m.^{2}hr. °C.) = 0.205 (Btu)/(ft.^{2}hr. °F.)

When the temperature-sensitive element is suddenly exposed to a new temperature, T_m, its surface does not immediately assume this temperature because of the insulating effect of the surface film. The solution of the partial differential equation for this condition involves the use of infinite series and is rather complicated and laborious to effect by direct calculation. It can be shown that the unconsumed temperature difference ϕ, can be expressed by

$$\phi = \theta/\theta_0 = (T_m - T)/(T_m - T_0) = f(\alpha t/R^2), (hR/k) \quad . \quad . \quad (1)$$

In Equation (1) the parameters $\alpha t/R^2$ and hR/k are dimensionless and a consistent set of units must, therefore, be used for evaluating them. Fig. 1 presents the graphical solution of Equation (1) and is taken from a paper by Alfred Schack. The ordinates to the curves give the unconsumed temperature difference for different values of the dimensionless parameter $\alpha t/R^2$ with values of the dimensionless product hR/k as abscissas.

From these curves the variation in the temperature at the axis of the measuring element can be calculated for different values of thermal diffusivity, α, surface heat transfer coefficient, h, and thermal conductivity, k. When all of these factors are known the time required for the unconsumed temperature difference, ϕ, to reach any specified value is readily calculated. In other words, the thermometric lag can then be determined for a wide range of operating conditions.

The use of the curves of Fig. 1 is illustrated by their application to the specific case of a 10-mm. radius cylinder for which $k = 0.25$, the product $c\rho = 1000$, and the surface heat transfer coefficient is 10 kg. cal. $m^{-2} hr.^{-1} °C.^{-1}$. Thus:

$$hR/k = (100 \times 0.01)/0.25 = 4.0$$

$$\alpha = k/\rho c = 0.25/1000$$

For the value $hR/k = 4.0$ the following values are obtained for $\alpha t/R^2$ and ϕ:

$\phi = \theta/\theta_0$	$\alpha t/R^2$	t (sec.)
0.93	5.0	7200
0.12	3.0	4320
0.25	2.0	2870
0.35	1.5	2160
0.53	1.0	1440
0.61	0.8	1150
0.72	0.6	860
0.825	0.4	575
0.91	0.25	358
0.97	0.15	215

The variation in ϕ with elapsed time is presented in Fig. 2.

Notation

T_m = constant temperature of surroundings (fluid medium)
T = temperature of axis of measuring element varying with time.
T_0 = initial temperature of axis of measuring element at time $t = 0$.
$\theta = T_m - T$
$\theta_0 = T_m - T_0$
$\phi = \theta/\theta_0$ = unconsumed temperature difference.
$\alpha = k/\rho c$ = thermal diffusivity ($L^2 T^{-1}$)
k = thermal conductivity (B.t.u. $hr.^{-1} ft.^{-1} °F.^{-1}$) or (kg. cal. $hr.^{-1} m.^{-1} °C.^{-1}$)
h = heat transfer coefficient (B.t.u. $hr.^{-1} ft.^{-2} °F.^{-1}$) or (kg. cal. $hr.^{-1} m.^{-2} °C.^{-1}$)
ρ = density (slug $ft.^{-3}$) or ($kg.m.^{-3}$)
c = specific heat (B.t.u. slug $^{-1} °F.^{-1}$) or (kcal. $kg.^{-1} °C.^{-1}$)
g = acceleration due to gravity (ft. $sec.^{-2}$) or ($m.sec.^{-2}$)
R = radius of cylinder (ft.) or (m.)
t = time (seconds)
f = function

3. Criterion of Thermometer Response Characteristics

The temperature response characteristics of different temperature sensitive elements can be compared on the basis of the time required for each to reduce the unconsumed temperature difference to some specified value. All of the measuring elements being subjected to the same initial temperature difference $(T_m - T_0)$. Obviously the selection of the critical value for ϕ is arbitrary.

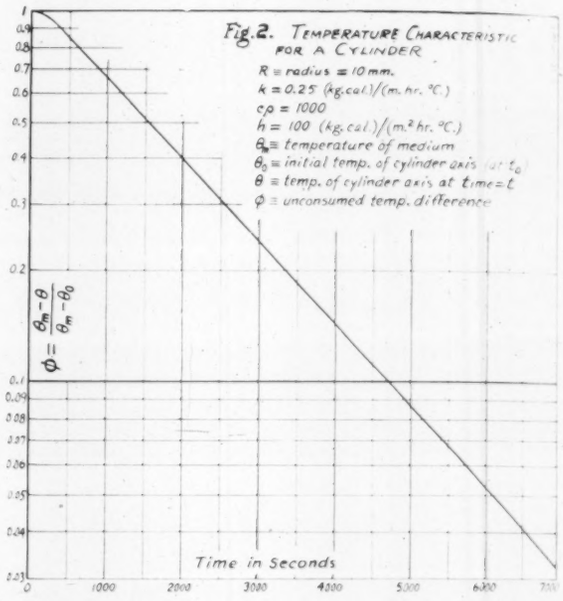
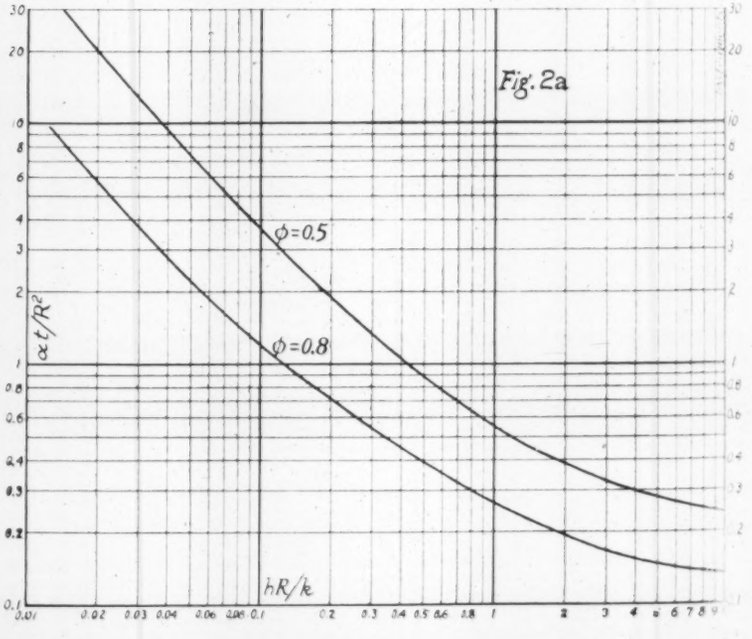


Fig. 2. Temperature Characteristic for a Cylinder
R = radius = 10 mm.
k = 0.25 (kg.cal)/(m. hr. °C.)
cρ = 1000
h = 100 (kg. cal.)/(m.² hr. °C.)
θm = temperature of medium
θ0 = initial temp. of cylinder axis (at t0)
θ = temp. of cylinder axis at time = t
φ = unconsumed temp. difference
φ = (θm − θ)/(θm − θ0)
Time in Seconds
0
1000
2000
3000
4000
5000
6000

Fig. 2a presents curves showing the variation of the dimensionless variable $\alpha t/R^2$ as a function hR/k for $\phi = 0.5$ and $\phi = 0.8$. As already pointed out, a consistent set of units must be used in evaluating the above dimensionless variables.

Fig. 3 shows the effect of thermal conductivity, k, and heat transfer coefficient, h, upon the time for a cylinder having $R = 10$ mm. and $C\rho = 1000$ to attain the value $\phi = 0.5$. The time to reach $\phi = 0.5$ is plotted as ordinate and the value of h as abscissas. The thermal conductivity is used



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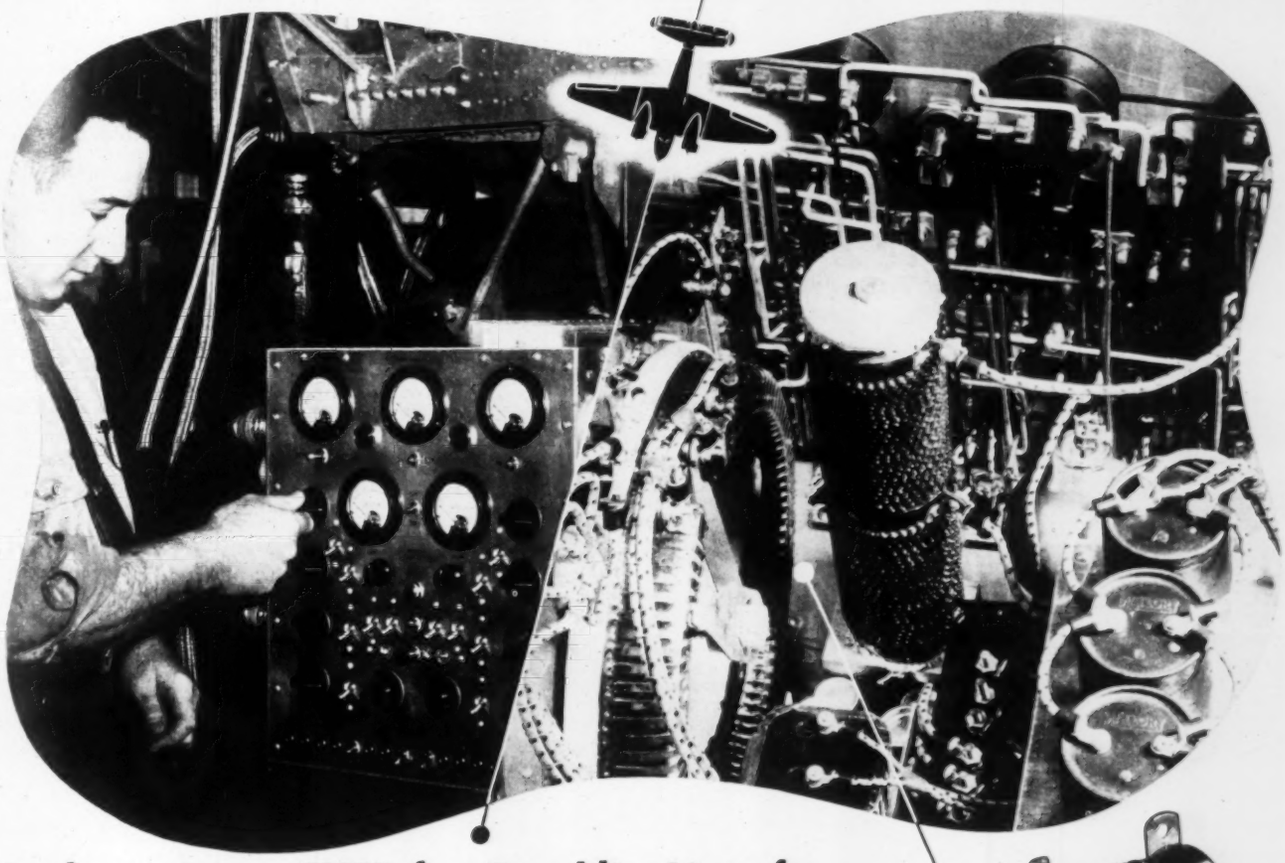

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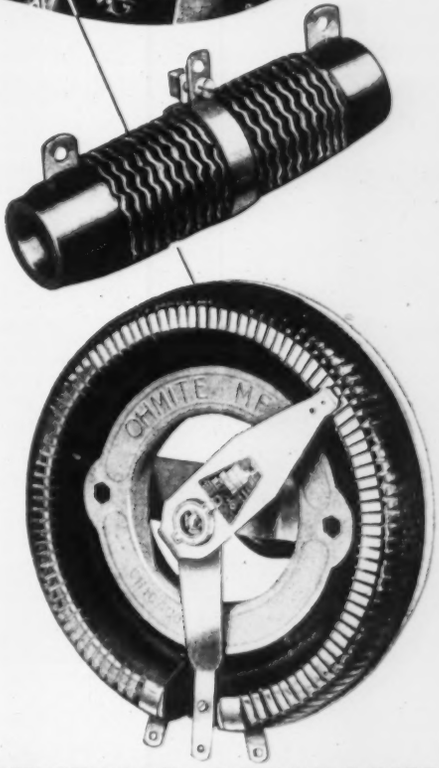

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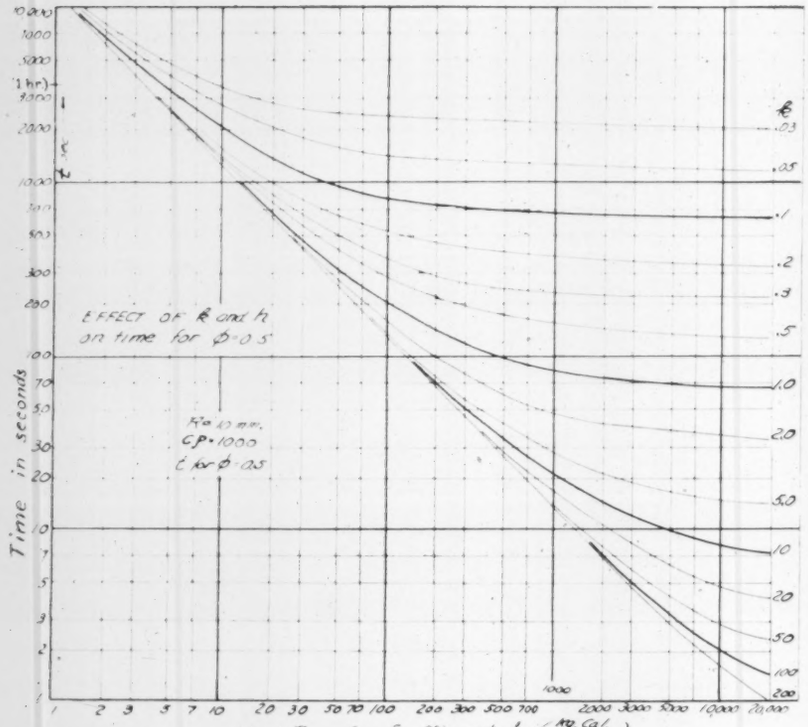

k in $\frac{Kg.Cal.}{m\,hr\,°C.}$; c in $\frac{Kg.Cal.}{Kg.°C.}$, ρ in $\frac{Kg.}{m^3}$

(k) $1 / \frac{Kg.Cal.}{m\,hr\,°C.} = 0.672 \frac{BTU.}{ft\,hr\,°F.}$; (c) $1 / \frac{Kg.Cal.}{Kg.°C.} = 1 / \frac{BTU.}{lb.°F.}$

(h) $1 / \frac{Kg.Cal.}{m^2hr°C.} = 0.205 \frac{BTU.}{ft^2hr°F.}$; (ρ) $1 / \frac{Kg.}{m^3} = 0.0625 \frac{lb.}{ft^3}$

Fig. 3 TIME FOR $\phi = \frac{\theta}{\theta_0}$ TO BECOME 0.5 FOR CYLINDERS

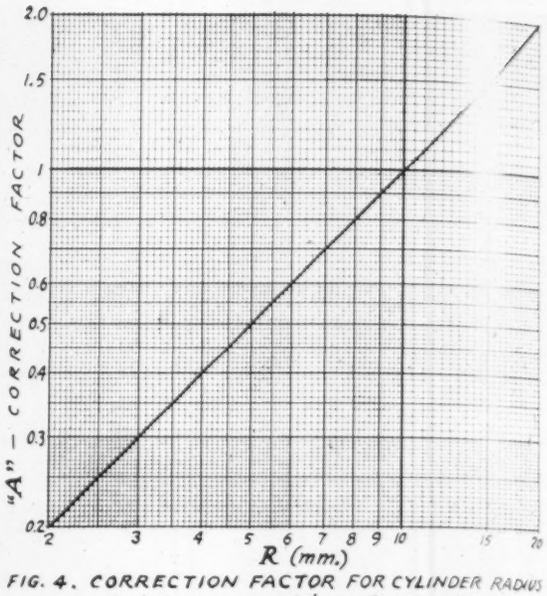

FIG. 4. CORRECTION FACTOR FOR CYLINDER RADIUS
Multiply actual value of h by Factor "A" to obtain h_c, the value of h for use with Fig. 3

as a parameter. This curve is taken from a paper by Fr. Lieneweg.

It is of interest to note the effect of the heat transfer coefficient upon the time required for $\phi = 0.5$. The curves demonstrate that any statement of thermometric lag is of little value unless accompanied by data pertaining to the predominating surface heat transfer coefficient.

The curves show that the temperature-sensitive assembly should be constructed of materials having high thermal diffusivity and they also demonstrate the importance of securing good heat transfer conditions at the installation location. It is seen that large values of the heat transfer coefficient, h_c, are more effective in reducing the time required to attain specific value of the unconsumed temperature difference in the case of high thermal conductivities than for low thermal conductivities. Furthermore, if the installation is highly unfavorable from the heat transfer standpoint (low values of h), large thermometric lags will be experienced even with assemblies having high thermal conductivities.

4. Determination of Time for $\phi = 0.5$

The curves of Fig. 3 apply to a cylinder having a radius $R = 10$mm. To apply them to cylinders of different radii, it is noted that for a given value of ϕ a specific value of hR/k always corresponds to the same value of $a\tau/R^2$ regardless of the individual magnitudes of h and R. Consequently, increasing the value of R results in a decrease in the value of h to be used in determining the time of $\phi = 0.5$ and conversely decreasing R increases its value; the relation being a reciprocal one. The factor by which the actual value of h must be multiplied to obtain that, denoted by h_c, to be used in Fig. 3 when determining the time for $\phi = 0.5$, can be obtained from Fig. 4.

To find the time for a measuring element to reduce the temperature difference to one-half its initial value in any medium, the first step is the determination of the overall conductivity of the element. This is accomplished by making an actual test and measuring the time for $\phi = 0.5$, with two different values of the surface heat transfer coefficient h; such as determinations in still water and in still air. If more convenient, the same medium can be employed with two different velocities past the element. The initial temperature difference should be large enough to permit an accurate measurement of the elapsed time.

The procedure is illustrated by the following example. Suppose from actual test, the times for $\phi = 0.5$ for an element having a radius of 5 mm. are—

In still water	95 sec.
In still air	550 sec.

The corresponding values of h for these conditions are 980 and 12.7 (kg. cal. m.$^{-2}$hr.$^{-1}$C.$^{-1}$) respectively. The ratio of the above times is $550/95 = 5.8$.

Since the curves of Fig. 3 are drawn for $R = 10$ mm. The correction factor to be applied to the actual values of h is from Fig. 4, $A = 0.5$. Hence, the values of h_c to be used with Fig. 3 are 490 and 6.75.

Using the latter values, a value of k must be determined from Fig. 3, which will give the same time ratio (5.8) that was obtained from the test. This can be determined by selecting several values of k and for the values of $h_c = 6.75$ and $h_c = 490$, noting the times and determining their ratios. Thus:

	Time (Sec.)		Time
	$h_c = 490$	$h_c = 6.75$	Ratio
k	Water	Air	Air/Water
0.1	680	2800	4.1
0.2	380	2250	5.9
0.3	250	2200	8.8

It is seen that the thermal conductivity for this element is very close to $k = 0.2$ (kg. cal. m.$^{-1}$hr.$^{-1}$C.$^{-1}$).

Now suppose it is desired to determine the time for $\phi = 0.5$ when the element is measuring air at 100 °C. flowing at 10 m./s. For this condition $h = 90$ (See Table 2) but for use with Fig. 3, its value is multiplied by $A = 0.5$, or the value of h_c is 45 (kg. cal. m.$^{-2}$hr.$^{-1}$C.$^{-1}$). The time corresponding to $h_c = 45$ is 700 sec.

From the preceding, it was found that for $k = 0.2$ the time corresponding to immersion in still water is 380 seconds. The ratio of the times, air/water, if $700/380 = 1.8$. Consequently, the time for this element to reduce the ten

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Measuring the Coulomb and Viscous Components of Friction

By CHARLES KENNEDY
Daniel Guggenheim Aeronautical Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

Editorial Foreword for Non-mathematical Readers

FRICTION is the commonest enemy of accuracy in the measurement of variables—and also a vicious enemy of close control in the automatic control of variables. Therefore the conquest of friction is not only an ideal of instrument-makers but an every-day objective of instrument users. Which is to say that the subject of Mr. Kennedy's article is of interest to every reader of *Instruments*.

What we call "friction" seldom is only one effect and in order to measure it we must analyze it as we would a chemical compound. Total friction generally is made up of several components, among them two whose importance overshadows all others—because in most practical cases all others can be considered as included in either one.

1. *Coulomb friction* (termed in some texts "solid" friction, "ordinary" friction, "sliding" friction or "mechanical" friction) is the force which opposes the relative motion of two dry surfaces in sliding contact and which therefore tends to stop such relative motion. It is different from "starting" friction. Its value is less than that of "starting" friction. In most practical cases, its value is independent of speed except at "extremely low" or "extremely high" speeds —and these extremes may be defined simply as outside the range of most practical cases. This is merely a convenient definition which dismisses extreme conditions, but it is justified because "pure" Coulomb friction is that between carefully-prepared surfaces operated under a high vacuum. Since practical work is not done in a vacuum, it is permissible to neglect "starting" friction in considering the "Coulomb *component*" of *total* friction from the energy-loss standpoint—as Mr. Kennedy does in this article which deals with the oscillations of the indicating elements of measuring systems, that is to say, with motions that stop and reverse—not with continuous motions.

2. *Viscous friction* is also known as fluid friction but it is more commonly known as viscous *damping* (or eddy-current damping) when the subject under study is the dying down of the oscillations of an instrument pointer. Unlike the value of Coulomb friction, the value of viscous friction or electromagnetic damping is zero when there is no relative motion between the surface involved; and it increases with speed.

3. "Turbulent friction," mentioned by Mr. Kennedy, is a component of damping rather than of friction in a measuring instrument. It is proportional to the square of the speed of the damping vanes. Its effect, in most practical cases, is completely masked. Outside the field of instrumentation it finds many uses, a familiar one being the butterfly type governor on a clock-chime motor.

4. "Structural damping" which he mentions at the end is an aeronautical-laboratory term denoting an energy-dissipation effect of importance in the study of wing flutter. Your editor believes that it is the same thing as what we call "internal damping" in the study of elastic members of instruments. At constant frequency of oscillation, "structural damping" is proportional to amplitude of displacement, not velocity—but since amplitude varies with velocity, "structural damping" (internal damping ?) appears to be proportional to velocity and hence undistinguishable from viscous friction (viscous damping).

Therefore, in an elementary instrument (mass-spring-damping system) *in motion*, the value of the Coulomb component remains constant; the instantaneous value of the viscous component is proportional to speed; and the instantaneous values of starting friction and of the turbulent component may both be neglected. What Mr. Kennedy says in this article, then, may be summarized as follows:

Start your instrument oscillating. Record the behavior of the pointer as its oscillations die down—not necessarily to zero but long enough to provide three or more *measurable peaks. The curve through the peaks will not be the straight line of Coulomb friction, nor the pure exponential curve of viscous damping, but it will lie between these two. On semi-log paper, however, an exponential curve plots as a straight line, and this provides a means of determining both the viscous component and the Coulomb component, because the graphic effect of the addition of Coulomb friction to viscous damping is to change the exponential to an exponential minus a constant. (See Fig. 1a of Mr. Kennedy's article.) That constant may be found by trial and error, making use of the fact that* it *will give a straight line on a semi-log plot when added to the value of each peak of the measured response curve. The viscous damping ratio may be found from the slope of the resulting line and the Coulomb friction force obtained from the constant added.*

To non-mathematical readers, the foregoing paragraph began easy but probably ended tough. The difficulties are more apparent than real and in that paragraph we purposely shifted from an informal style to some of Mr. Kennedys' own expressions in order to smooth your way. For your sake, by the way, Mr. Kennedy re-wrote much of his article after he first submitted it to your editor; and he put practically all his mathematics in an appendix. All you need to know is how to plot a series of points on two kinds of graph paper: the plain kind and the semi-log kind. Then you can follow Mr. Kennedy's directions without having to grasp the underlying mathematical theory. By purely graphic means and without even going through the whole graphic procedure he recommends, you will be able to determine the extent to which the pure damping of your instrument (which does *not* produce a final error) is affected by common friction (which *does* prevent the pointer or pen-arm from coming to rest where it should.)

The practical difficulty of applying Mr. Kennedy's method to non-recording instruments consists in obtaining a record of the oscillations of a pointer without making the pointer heavier and without further impeding its freedom. One solution is to use a motion-picture camera. Placing a stop-watch (or electric stop-clock) next to the instrument under study will make it possible to use an ordinary "amateur movie" instead of a special type.

In studying the oscillations of the pen-arm of a recording instrument, it may be necessary to disconnect the regular chart drive (inches-per-hour) and rig up a means of driving the chart at a speed of several inches per second, which need not be uniform.

—M. F. BEHAR

THE usual method for determining the damping in a mass-spring-damping system such as an elementary instrument is to make measurements on the transient* resulting when a step function is applied; that is, when the measured variable is suddenly changed from one value to another. If the system oscillates before coming to rest, the damping is said to be less than critical. That is the case treated in this article. The decrease per semi-cycle in potential energy stored in the spring, as indicated by the decrease in the peak values of the amplitude, is equal to the energy dissipated by the friction forces during the semi-cycle.

Coulomb friction is constant and independent of velocity while there is motion. It will cause the line through the peaks of the response curve to be straight, sloping downward at the rate of 4 x_{cm} per cycle. (Fig. 1a.) In this figure [reproduced full-size—ED] x_{cm} is the distance, to the scale of the record, that the constant Coulomb friction force F could stretch the spring, which has stiffness k.[1] Rather than use the line through the peaks, it is easier to measure

*A "transient," in this case, is the behavior of the pointer or pen-arm.—EDITOR.

[1] J. P. Den Hartog. Mechanical Vibrations. McGraw Hill Book Co., New York.

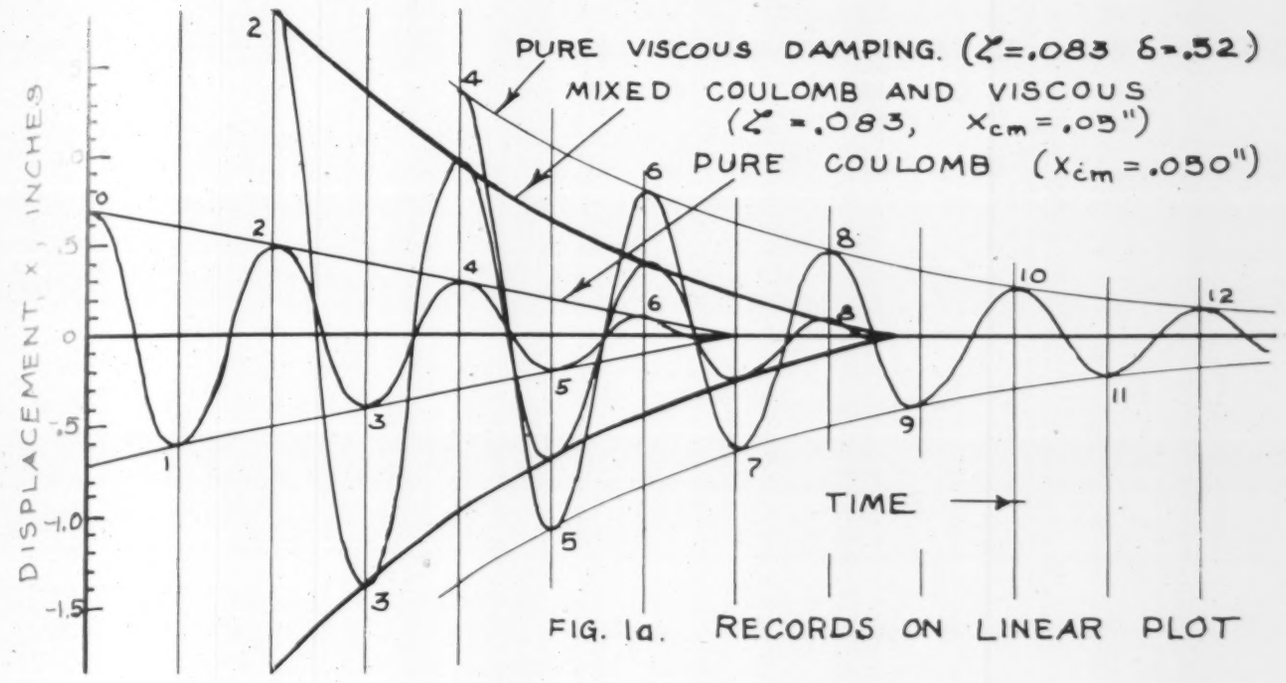


FIG. 1a. RECORDS ON LINEAR PLOT

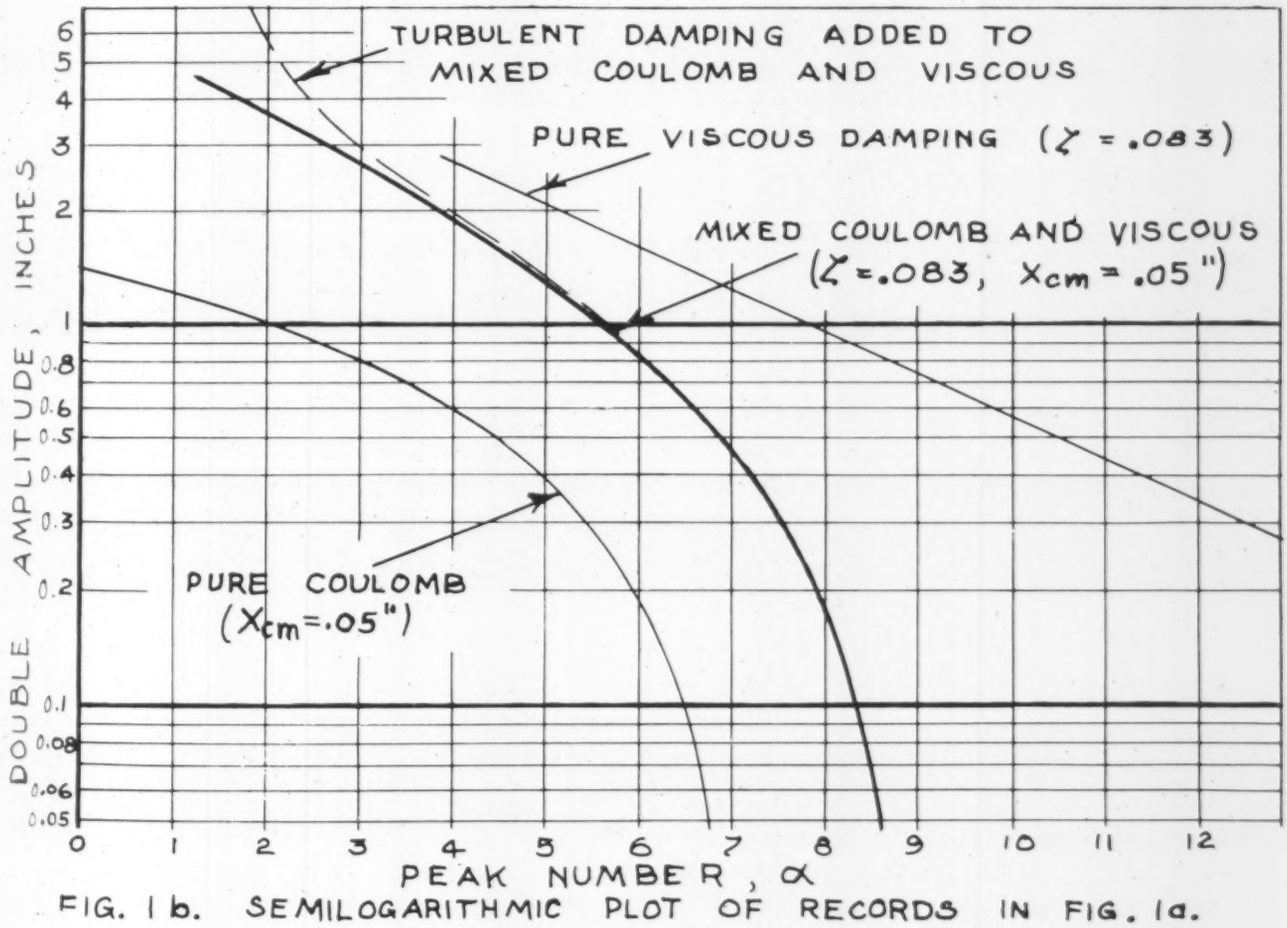


FIG. 1b. SEMILOGARITHMIC PLOT OF RECORDS IN FIG. 1a.

Fig. 1. Response Curves for a Mass-spring-damping System with Various Kinds of Damping. (Full-size reproduction.)

the double amplitude because this obviates the need of first locating the mean from which to measure peaks. The double amplitude decreases constantly at the rate of 8 x_{cm} per cycle, but, if plotted on a logarithmic scale against peak number α, it will no longer follow a straight line but will curve downward and approach a vertical asymptote at the peak number when the double amplitude is zero. (Fig. 1b.)

When only viscous friction, proportional to velocity, is present, the double amplitude is a pure exponential curve which, when plotted on a logarithmic scale against peak number, becomes a straight line. (Fig. 1.)[1,2] One commonly used measure of the viscous damping is the logarithmic

[2] C. S. Draper & G. V. Schliestett, General Principles of Instrument Analysis, *Instruments*, Vol. 12, May 1939, pages 137-142.

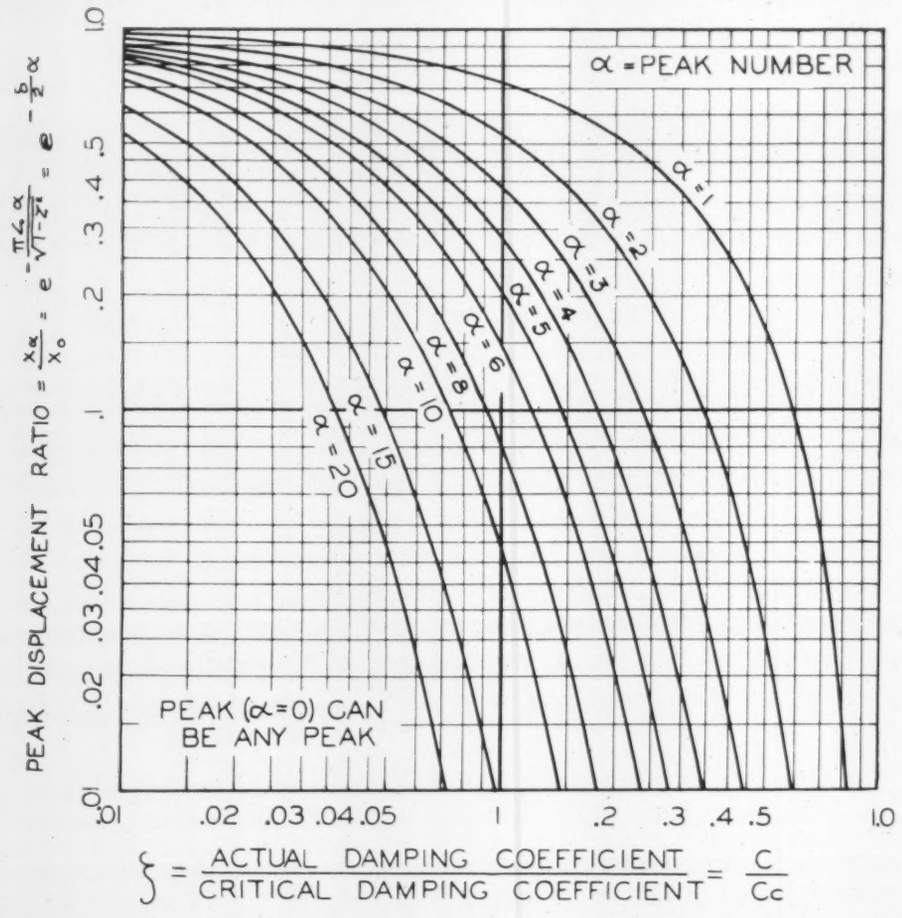

α = PEAK NUMBER
α = 1
α = 2
α = 3
α = 4
α = 5
α = 6
α = 8
α = 10
α = 15
α = 20
PEAK (α = 0) CAN BE ANY PEAK
PEAK DISPLACEMENT RATIO = $\frac{x_\alpha}{x_0} = e^{-\frac{\pi\zeta\alpha}{\sqrt{1-\zeta^2}}} = e^{-\frac{\delta}{2}\alpha}$
.01 .02 .03 .04 .05 .1 .2 .3 .4 .5 1.0
$\zeta = \frac{\text{ACTUAL DAMPING COEFFICIENT}}{\text{CRITICAL DAMPING COEFFICIENT}} = \frac{C}{C_c}$

Fig. 2. Peak Disp... ent of Ratios of O... ory Transients as a ... ion of Damping Ratio

decrement δ, defined as the natural logarithm of the constant ratio between successive positive peaks, or between double amplitudes at the beginning and end of a cycle. Another measure of the damping is the damping ratio ζ (zeta), defined as the ratio of the actual damping coefficient c to the critical damping coefficient c_c that is just large enough to prevent oscillation. (ζ is used extensively in the M. I. T. instrument work because the general form of the step function response curve for a given value of ζ is easily remembered, ζ remains real for non-oscillatory cases, and especially because it is simply related to the constants of the system.) ζ may be found from a step function response curve by the chart, Fig. 2.[2]

When the two kinds of friction are both present, the line through the peaks and the double amplitude will be curved on either kind of plot (Fig. 1), but the equation of the line through the peaks is changed from the pure exponential only by the subtraction of a constant difference D; or the lines through the upper and lower peaks for pure viscous friction are brought together a distance $2D$ when the Coulomb friction is added.

To prove this we must start with the equation of motion for the elementary instrument characterized by both types of friction. For simplicity of writing, without affecting the generality, assume that the initial position of the pointer or pen-arm is x_0 and that the pressure or other measured variable suddenly drops to zero. The equation is then:

$$md^2x/dt^2 + cdx/dt + kx \pm F = 0 \quad (1)$$

where m, c, and k, are effective or equivalent average values of the mass, damping coefficient, and spring constant, respectively. The $\pm F$ indicate that although the Coulomb friction force is constant in magnitude it changes sign abruptly when the velocity changes direction; consequently the motion can be considered only half a cycle at a time. The upper sign (+) is taken to correspond to a positive velocity. For the first half cycle the velocity is negative, the lower sign (−) is taken, and the equation, after rearranging, is given with the complete mathematical derivation in the ap-

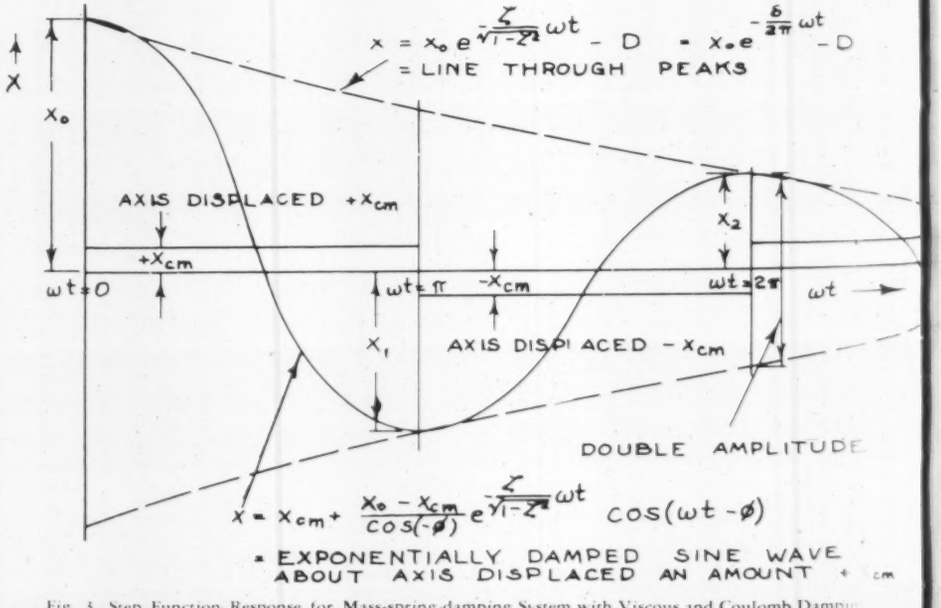
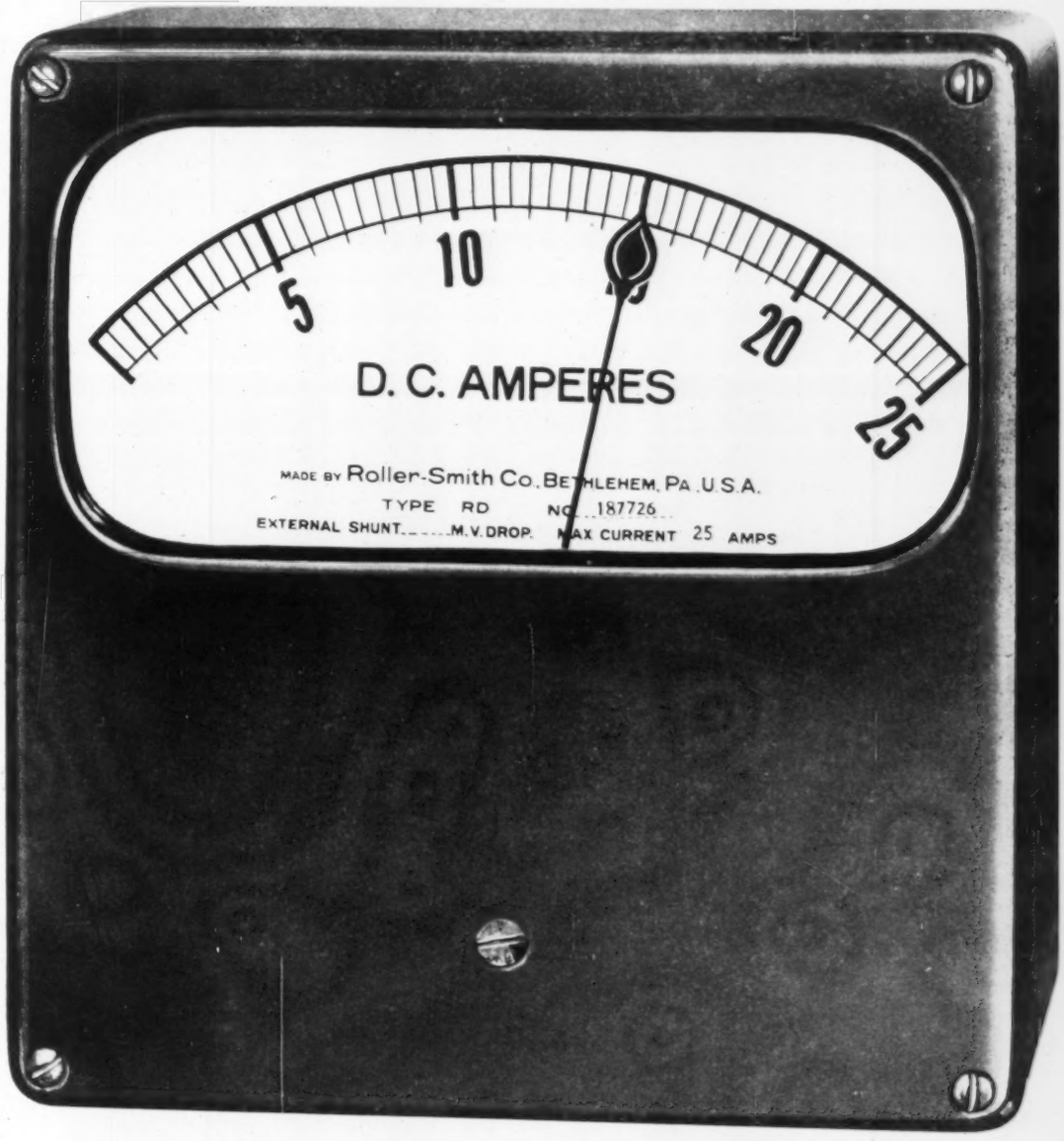

$x = x_0 e^{-\frac{\zeta}{\sqrt{1-\zeta^2}}\omega t} - D = x_0 e^{-\frac{\delta}{2\pi}\omega t} - D$
= LINE THROUGH PEAKS
X
X_0
AXIS DISPLACED $+X_{cm}$
$+X_{cm}$
X_2
$\omega t = 0$
$\omega t = \pi$
$-X_{cm}$
$\omega t = 2\pi$
ωt
X_1
AXIS DISPLACED $-X_{cm}$
DOUBLE AMPLITUDE
$x = x_{cm} + \frac{x_0 - x_{cm}}{\cos(-\phi)} e^{-\frac{\zeta}{\sqrt{1-\zeta^2}}\omega t} \cos(\omega t - \phi)$
= EXPONENTIALLY DAMPED SINE WAVE ABOUT AXIS DISPLACED AN AMOUNT + cm

Fig. 3. Step Function Response for Mass-spring-damping System with Viscous and Coulomb Dampi...

Can You Read This Dial
FROM 15 FEET?



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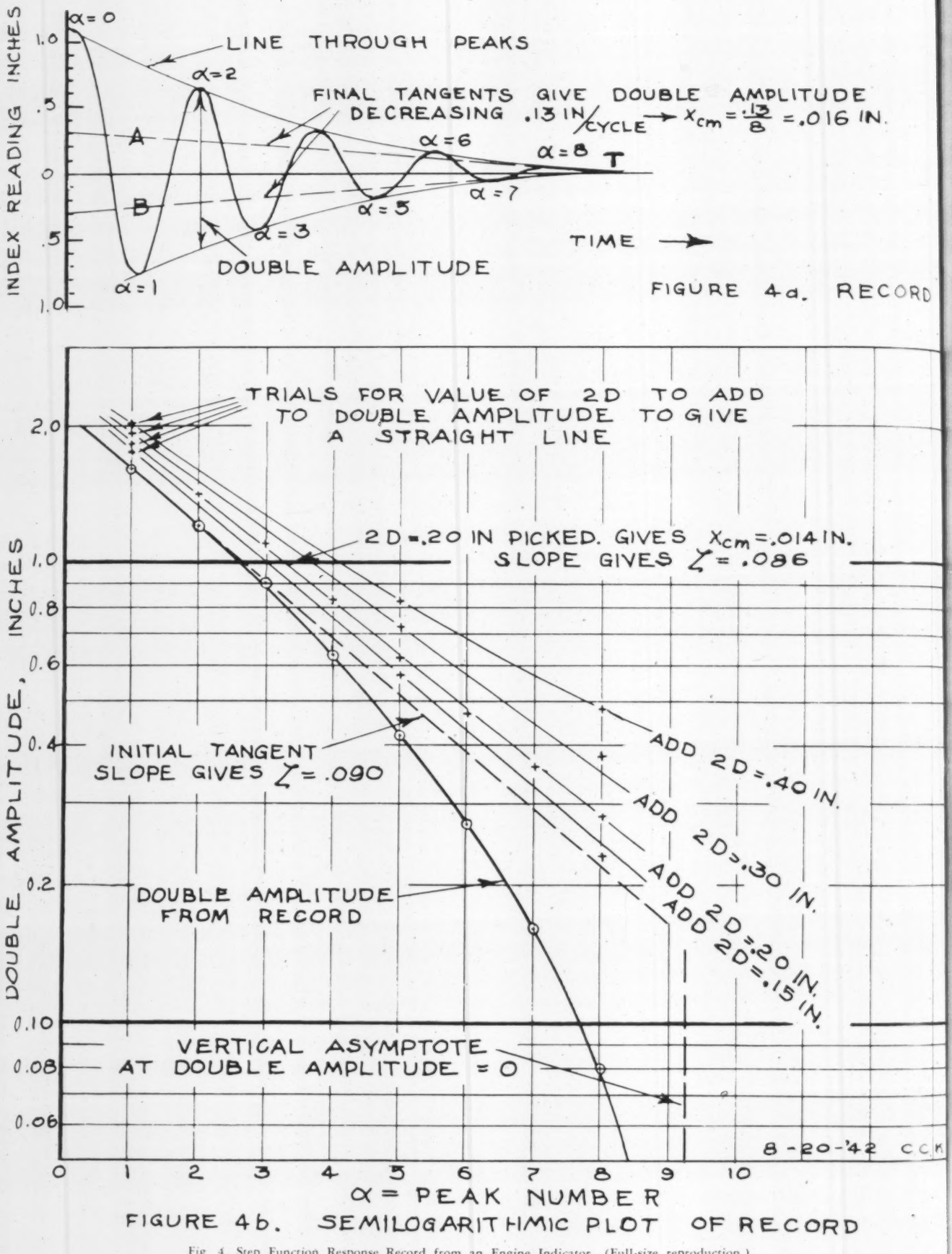

Fig. 4. Step Function Response Record from an Engine Indicator. (Full-size reproduction.)

pendix (Equation 2). The right-hand side of the equation is constant (during the half cycle), hence the solution (Equation 4) is the usual solution for pure viscous damping, except that the axis of the curve is displaced by an amount $+x_{cm}$ (see Fig. 3). The equation of motion is solved for the first peak value x_1, at the end of a half-cycle, in terms of the zeroth peak x_0 by substituting $\omega t = \pi$, (Equation 5) and a general formula for the αth peak in terms of the $(\alpha-1)$th peak, occurring just before it, is given by Equation 6.

From this general form, the expression for the ath peak in terms of the peak $a=0$ must be obtained. To do so, x_1 is found in terms of x_0 (Equation 7). Then x_2 is found in terms of x_1 and the value just found for x_1 is substituted, giving x_2 in terms of x_0. (Equations 8.) Then x_3 is found in terms of x_2 and the value of x_2 is substituted, giving x_3 in terms of x_0 (Equations 9), and so on until a pattern of the general form takes shape and the general relation for the ath peak can be derived by mathematical induction (Equation 10). This is rearranged, and the absolute value of the peak is given in Equation 11, which has the form of an exponential plus a constant minus a brace {} of terms.

As more and more terms are taken in the brace {}, the amount added becomes less and less and it quickly converges to a constant value. Being a geometric progression, the sum of an infinite number of terms is easily found (Equation 12). Hence, if the zero peak be taken farther and farther back from the section of the curve under consideration, the form of the absolute value of x_a approaches more and more closely an exponential minus a constant.

The peak chosen as zero can be any peak and, as far as the analytical expression is concerned, it may even be one occurring (in the imagination only) long before the first peak on the actual record. Thus if a is measured from minus infinity, the expression for x_a is given in Equation 13, and it is seen to be an exponential minus an expression D, which is constant.

Thus it has been shown that the equation of the line through the peaks is an exponential with a logarithmic decrement equal to that which would occur if there were no Coulomb friction present, minus a constant difference D.

To illustrate the method, an actual record in which an indicator* has been subjected to a sudden change in pressure, from 44 lbs./in.^{2} to zero, is given in Fig. 4a. The lines through the peaks are drawn (the envelopes to the curve would do equally well in this as in most practical cases) and the double amplitudes are measured and plotted to an entirely arbitrary scale on semi-log graph paper in Fig. 4b.

(It might seem more natural to measure single amplitudes from the zero line since it is already provided by the indicator; but if this is done the points lie alternately above and below the smooth curve through them. This indicates that the pointer, which can come to rest anywhere within the band of uncertainty defined by $\pm\ x_{cm}$, has stopped slightly below the true zero.)

Adding $2D = 0.40''$ to each *double* amplitude and plotting directly on the same graph, $0.40''$ is seen to be too great because the new line curves outward. Trying successively $2D = 0.30''$, $0.20''$, and $0.15''$, $2D = 0.20''$ is seen to give as near a straight line as the uncertainty of the points permits. The ratio of peak 8 to peak 2 on the imaginary purely viscous damping curve indicated by this straight line is $0.27/1.39 = 0.194$. This peak ratio on the line $a = 6$ in Fig. 2 gives $\zeta = 0.086$ and $\delta = 2\pi\zeta = 0.54$. (Simply taking ζ corresponding to the initial slope is often satisfactory and gives in this case $\zeta = .090$.)

Professor W. McKay of M.I.T. has pointed out that because the equation of the envelope is an exponential plus a constant, its first derivative with respect to peak number or time is a pure exponential. Hence plotting differences between successive peak values on semi-log paper will give a straight line with the desired slope. This provides a rigorous and straightforward method for finding ζ and eliminates the trial and error.

Using $\zeta = 0.086$ and $a = 1$ in the same chart gives

$$\exp\left[-\pi\zeta/(1-\zeta^2)^{-2}\right] = e^{-\delta/2} = 0.76.$$

$$\text{Then } x_{cm} = \left[(1-e^{-\delta/2})/(1+e^{-\delta/2})\right]D$$
$$= \left[(1-0.76)/(1.76)\right](0.10) = 0.014''.$$

The spring constant k is 40 pounds per inch, so the friction force, F, equals kx_{cm} and $F = 40\ (0.014) = 0.6$ pounds.

The expression for x_{cm} can be greatly simplified for small ζ by expanding $e^{-\delta/2}$ into a series and neglecting second order terms, giving $x_{cm} = (\pi/2)\zeta D = (\delta/4)D$. The approximation is less than 1% too high for ζ less than 0.1 or δ less than 0.63.

Because the effect of viscous friction compared to the Coulomb is eliminated as the amplitude and velocity approach zero, the slope of the line through the peaks approaches the value it would have if only Coulomb friction were present. Hence x_{cm} may also be found by drawing the final tangents TA and TB (Fig. 4a) and finding that a transient with only the Coulomb friction present would die to zero from $0.60''$ double amplitude in 9 semi-cycles, or that the double amplitude decreases at the rate of $(0.60 \times 2)/9 = 0.13''$ per cycle and $x_{cm} = 0.13/8 = 0.016''$. The difference from the previous value, $0.014''$, is a large percentage but it is smaller than the uncertainty of the individual scale readings which were measured to $0.01''$; that is the reward for using curves through a large number of readings.

The method of drawing the final tangents is to be used especially when the Coulomb is large compared to the viscous and a large portion of the transient is nearly linear.

The plotting of transients on a semi-logarithmic graph is to be recommended even when it is not desired to find the components of friction. The uncertainty of peak readings is most easily judged and allowed for when the plot is most nearly a straight line. Selection of an equivalent viscous damping ratio to fit any desired amplitude can best be done by drawing at that amplitude the tangent to the curve plotted on semi-log paper, because the closeness to which the equivalent value fits other amplitudes in the range of operation can be estimated by comparing slopes.

To back-figure transients, knowing ζ or δ and x_{cm}, plot the pure viscous component on semi-log paper, locating the straight line with two points in a ratio determined from the peak value chart, then calculate D and subtract it directly on the same plot. Equivalent viscous damping ratios can then be found for any amplitude from the slope of the curve at that amplitude.

The effects of turbulent friction (proportional to velocity squared) can often be eliminated because, just as the effect of viscous friction compared to Coulomb friction disappears at low amplitudes and velocities, so does the effect of turbulent friction decrease more rapidly than that of viscous as the amplitude is decreased. This gives an outward curvature characteristic of friction proportional to higher powers of velocity than the first—a characteristic which is as easily detected on a semi-log plot as is the downward curvature characteristic of friction proportional to lower powers of velocity than the first.

When all three kinds of damping are present, the curve will have the characteristic shape shown in Fig. 1b. The right-hand portion can still be handled as if the turbulent friction were absent, unless the portion for which a record is obtained does not contain sufficiently small amplitudes that the turbulent friction may be considered negligible compared to the rest.

Mixtures of turbulent and viscous damping come up in measurements of structural damping (similar to viscous damping in its effect on the transient) made from free vibration of airplane wings in air. To the extent that the air damping is turbulent it can be eliminated by taking the slope that the damping curve approaches as the amplitude dies to zero.

Replotting viscous damping transients on semi-log paper provides also a means of detecting non-linearities in recording instruments. If the measured variable is a reliably viscous damping transient, departures from a straight line on the semi-log plot can be blamed on the non-linearity with amplitude of the recording apparatus.*

A record from an engine indicator was used as an example because it is a familiar and "elementary" instrument, but the information obtained is more detailed than neces-

*EDITOR'S NOTE:—Mr. Kennedy refers to an engine indicator, that is to say, a pressure *recording* instrument.—MFB.

*EDITOR'S NOTE:—Not always. Notable exceptions are found in temperature-measuring systems, etc., where the blame must be laid on the primary measuring element, not on the "recording apparatus." Analytical methods similar to the new one proposed by Mr. Kennedy have actually been used to determine the non-linearity of measuring systems by means of recording apparatus known to suffer from friction—such friction being relatively insignificant.—MFB.

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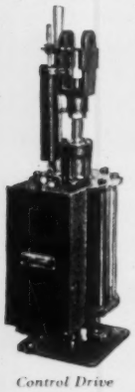

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sary for most purposes. More useful application can be made to the direct measurement of friction in such apparatus as airplane control systems, by supplying an external spring force large enough to give several peaks on the transient, and recording the motion with, say, an electrical strain gage on the external spring. The advant[illegible] breaking down the friction [illegible] Coulomb force and a viscous co[illegible] is that they can be recombined [illegible] the resultant total energy lo[illegible] cycle, or to give an equivalent f[illegible] coefficient, at any desired fre[illegible] and amplitude.

APPENDIX: DERIVATIONS AND EQUATIONS

The differential equation of motion is

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx \pm F = 0. \quad (1)$$

For the first half cycle, velocity and F are negative, giving

$$\frac{d^2x}{dt^2} + \frac{c}{m}\frac{dx}{dt} + \frac{k}{m}x = +\frac{F}{m} = \frac{k}{m}\frac{F}{k}, \quad (2)$$

or $$\frac{d^2x}{dt^2} + 2\zeta\omega_n\frac{dx}{dt} + \omega_n^2 x = \omega_n^2 x_{cm} \quad (3)$$

The solution is

$$x = x_{cm} + Ae^{\frac{-\zeta\omega_n t}{\sqrt{1-\zeta^2}}}\cos(\omega t - \phi). \quad (4)$$

A and ϕ are fitting constants determined by initial conditions. Substituting $x = x_0$ at $t = 0$, A is found to be $\frac{x_0 - x_{cm}}{\cos(-\phi)}$. Substituting $\omega t = \pi$ gives the first peak value x_1 in terms of x_0:

$$x_1 = x_{cm} - (x_0 - x_{cm})e^{\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}} = x_{cm} - (x_0 - x_{cm})e^{-\frac{\delta}{2}}. \quad (5)$$

The αth peak in terms of the $(\alpha-1)$th peak is

$$x_\alpha = -(x_{\alpha-1} + (-1)^\alpha x_{cm})e^{-\frac{\delta}{2}} - (-1)^\alpha x_{cm}. \quad (6)$$

To get the αth peak in terms of the peak $\alpha = 0$, values are found successively for $\alpha = 1, 2, 3$, and the general form is derived by mathematical induction.

For $\alpha = 1$

$$x_1 = \left[-(x_0 - x_{cm})e^{-\frac{\delta}{2}} + x_{cm}\right]. \quad (7)$$

For $\alpha = 2$

$$\begin{aligned} x_2 &= -\left\{x_1 + x_{cm}\right\}e^{-\frac{\delta}{2}} - x_{cm} \\ &= -\left\{\left[-(x_0 - x_{cm})e^{-\frac{\delta}{2}} + x_{cm}\right] + x_{cm}\right\}e^{-\frac{\delta}{2}} - x_{cm} \\ &= (x_0 - x_{cm})e^{-2\frac{\delta}{2}} - 2x_{cm}\left\{e^{-\frac{\delta}{2}}\right\} - x_{cm}; \end{aligned} \quad (8)$$

For $\alpha = 3$

$$\begin{aligned} x_3 &= -\left\{x_2 - x_{cm}\right\}e^{-\frac{\delta}{2}} + x_{cm} \\ &= \left\{\left[(x_0 - x_{cm})e^{-2\frac{\delta}{2}} - 2x_{cm}e^{-\frac{\delta}{2}} - x_{cm}\right] - x_{cm}\right\}e^{-\frac{\delta}{2}} + x_{cm} \\ &= -(x_0 - x_{cm})e^{-3\frac{\delta}{2}} + 2x_{cm}\left\{e^{-2\frac{\delta}{2}} + e^{-\frac{\delta}{2}}\right\} + x_{cm}; \end{aligned} \quad (9)$$

For $\alpha = \alpha$

$$x_\alpha = (-1)^\alpha(x_0 - x_{cm})e^{-\alpha\frac{\delta}{2}} - (-1)^\alpha 2x_{cm}\left\{e^{-(\alpha-1)\frac{\delta}{2}} + e^{-(\alpha-2)\frac{\delta}{2}} + \cdots + e^{-\frac{\delta}{2}}\right\} - (-1)^\alpha x_{cm} \quad (10)$$

The absolute value, rearranged, is

$$|x_\alpha| = (|x_0| + x_{cm})e^{-\alpha\frac{\delta}{2}} + x_{cm} - 2x_{cm}\left\{e^{-0\frac{\delta}{2}} + e^{-1\frac{\delta}{2}} + e^{-2\frac{\delta}{2}} + \cdots + e^{-(\alpha-1)\frac{\delta}{2}} + e^{-\alpha\frac{\delta}{2}}\right\}. \quad (11)$$

The bracket $\{\ \}$ is a geometric progression of first term $a = e^{-0\frac{\delta}{2}} = 1$, and ratio $r = e^{-\frac{\delta}{2}}$. The sum of an infinite number of terms is given by

$$S = \frac{a}{1-r} = \frac{1}{1-e^{-\frac{\delta}{2}}} \quad (12)$$

If α is measured from an imaginary zero at minus infinity,

$$\begin{aligned} |x_\alpha| &= (x_0 + x_{cm})e^{-\alpha\frac{\delta}{2}} - x_{cm}\left(\frac{1+e^{-\frac{\delta}{2}}}{1-e^{-\frac{\delta}{2}}}\right) \\ &= (x_0 + x_{cm})e^{\frac{-\alpha\pi\zeta}{\sqrt{1-\zeta^2}}} - x_{cm}\left(\frac{1+e^{\frac{\pi\zeta}{\sqrt{1-\zeta^2}}}}{1-e^{\frac{\pi\zeta}{\sqrt{1-\zeta^2}}}}\right) \end{aligned} \quad (13)$$

The quantity $x_{cm}\left(\frac{1+e^{-\frac{\delta}{2}}}{1-e^{-\frac{\delta}{2}}}\right) = x_{cm}\left(\frac{1+e^{\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}}}{1-e^{\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}}}\right) = D \quad (14)$

is constant, hence $|x_\alpha|$ is an exponential with logarithmic decrement equal to that which would obtain if there were no coulomb friction present, minus a constant.

DEFINITIONS OF SYMBOLS

m = mass coefficient
c = damping coefficient
k = spring coefficient
F = maximum coulomb friction force (occurring while there is motion)
$\zeta = \frac{c}{2\sqrt{km}}$ = damping ratio
α = peak number = $\pi\omega t$
$x_{cm} = \frac{F}{k}$
t = time
x = displacement on record (proportiortional to the displacement of any part of the system)
$\omega_n = \sqrt{\frac{k}{m}} = 2\pi$(undamped natural frequency)
$\omega = \sqrt{1-\zeta^2}\,\omega_n = 2\pi$(natural frequency)
$\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \cong 2\pi\zeta$ for small ζ
= logarithmic decrement

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By CAPTAIN RUSH A. BOWMAN

In charge of Pittsburgh Gage Laboratory, Ordnance Department, U. S. Army

CHAPTER V

POSITION AND ALIGNMENT DETERMINATION

No attempt will be made to discuss all types of gages used in determinations of position and alignment, because there are as many gages as there are problems. A position or alignment gage, in general, is an assembly of a number of different gages in one unit. For illustrative purposes, one gage involving most of the problems arising in position and alignment determinations will be discussed in detail.

One type of gage, however, may be definitely classified as a position and alignment determination gage; namely, the concentricity gage. This type, therefore, will also be treated in this chapter.

Position and alignment determinations involve, generally, the use of a gaging fixture. The purpose of the gaging fixture is a functional inspection of a component part. An attempt is made in every gaging fixture to simulate in so far as possible the conditions which will exist in an assembly.

A Typical Position and Alignment Problem

Fig. 1 shows a hypothetical but illustrative component part, and the fixture gage for inspecting it. The purpose of the gage is to determine that the part will function correctly. The mere fact that holes *A*, *B*, *C*, and *D* are the correct size is no indication that when parts are assembled into these holes, proper functioning will result. The specific purpose of the gage, then, is to show *which holes*, if any, are incorrectly positioned or aligned. The determinations required are: (1) The alignment of the bore *A* with the square hole *B*. (2) The alignment of bores *C* and *D* (which are coaxial) with the square hole *B*. (3) The position and alignment of the shoulder *E* with the center line of bores *B* and *C*.

(1) Alignment of bore A with the square hole B.

This alignment is determined by rigidly mounting on the same frame an expanding mandrel, *A*1, and a square plug, *B*1. The component part is placed over the expanding mandrel, and the mandrel is expanded by the drawing of one cone within another as shown in detail in Fig. 2. When this mandrel is expanded, the center line of the bore in the component should coincide with the center line of the expanding mandrel.

The component part is then swung on this mandrel until the square hole is in line with the square plug *B*1 which is shown in detail in Fig. 3. This plug *B*1 is then slid into this opening. The plug should fit freely with no forcing.

A new consideration in gage design is here involved. Let us suppose that the thickness of the hole in the part is 1.000″ + 0.002″. This plug should not serve as a sizing plug —the actual sizing of this hole should be accomplished with

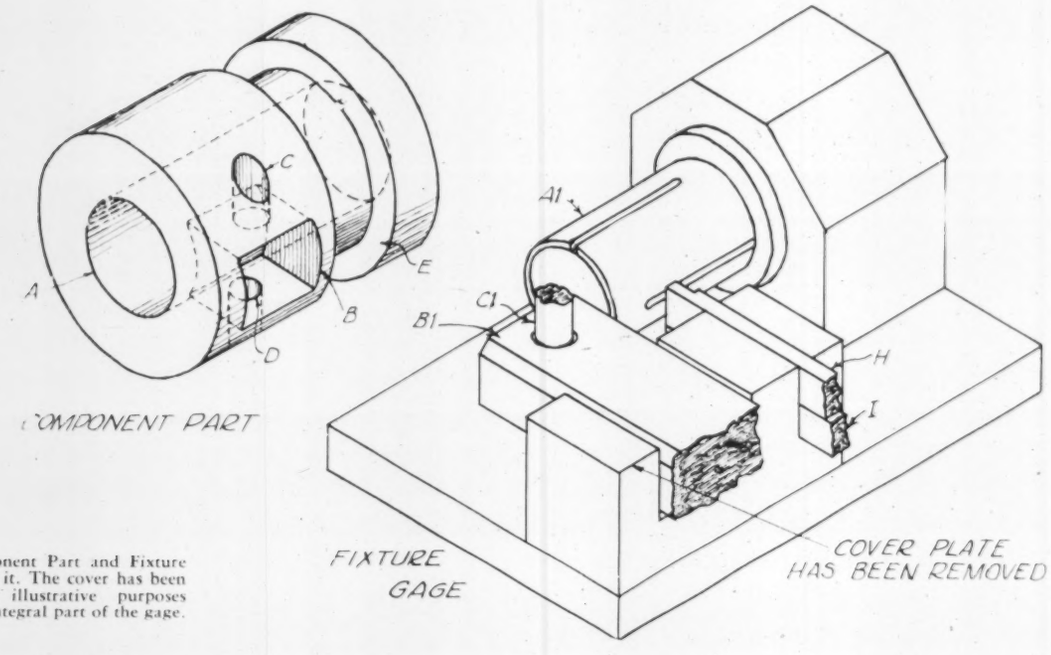

Fig. 1. Component Part and Fixture Gage to check it. The cover has been removed for illustrative purposes only. It is an integral part of the gage.

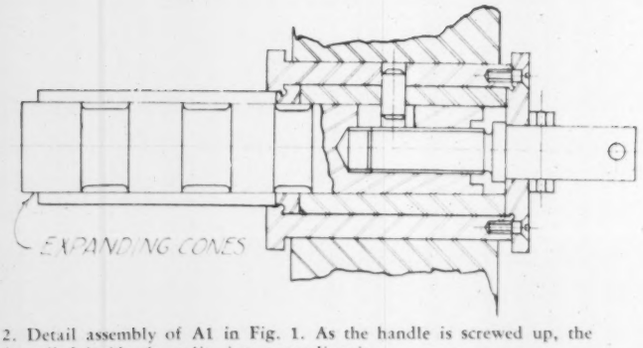

Fig. 2. Detail assembly of A1 in Fig. 1. As the handle is screwed up, the cone is pulled inside the split ring, expanding it.

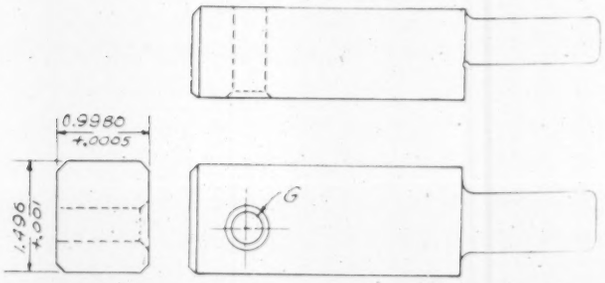

Fig. 3. Detail of square plug B1 in Fig. 1. Note chamfers on all edges.

...re plug gage whose size on the "go" dimension would ...001" + 0.0001". If this size were used on the plug in ...xture gage, it would unduly restrict the tolerances to ... the manufacturer could actually work. A rule is, ...fore, used in the determination of size for this plug:

Take 40% of the allowance between the male ...d female parts of a given assembly. For a gage ...easuring the female part, this percentage is sub...racted from the minimum size. For a gage meas...uring the male part, this percentage is added to ...e maximum size.*

There is no wear allowance on these gages.*

Gage tolerance is 10% of the allowance between the male and female parts. It is applied plus on the gage for the female part and minus on the gage for the male part.*

It will be readily seen that this is not only a fair but also a most logical solution to this problem. It is quite essential that due consideration be given the actual functioning of the part, and this rule is designed to do just that.

Pursuing this method, let us assume that the allowance between this hole and the part which moves in it is 0.005". Now 40% of this 0.005" is 0.002". This then is subtracted from the size of the hole with the result, 0.9980", as the basic size of the plug. 10% of this allowance is 0.0005"; and the plug is therefore dimensioned 0.9980" + 0.0005".

Furthermore, let us assume that the width of the hole in the part is 1.500" + 0.010", and that the part moving within it has a basic width of 1.490". Basic size of a gage would be the basic size of the part, 1.500", less 40% of ten thousandths, or 1.496". The tolerance (10% of the allowance 0.010") would be 0.001". And so the plug would be dimensioned 1.496" + 0.001". It should be noted that a chamfer is shown on the corners of the square plug. Reference to Fig. 1 will show that there are fillets in the corners of the square hole. The chamfers must, therefore, be taken on the corners of the plug in order to eliminate the possibility of interference. Radii or rounds could be made on the square plug in order to meet this contingency, but chamfers are the common practice, because they are more easily made and because they provide sufficient inspection in that they maintain a flat surface as far as the break of the radius.

(2) Alignment of bores C and D with square hole B.

This alignment determination is accomplished by means of a plug, one portion of it being of expanding design (See Fig. 4). After the square plug has been inserted in the square hole (See Figs. 1 and 3), the expanding plug shown

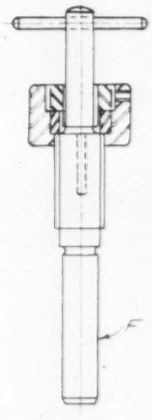

Fig. 4. Detail assembly of C1 in Fig. 1. As handle is screwed up, upper portion will expand. In assembly, surface F fits down through both G in square plug and D in component.

in Fig. 4 is inserted into the holes *C* and *D* in the component part. Surface *F* of the plug should be a snug, sliding fit in hole *G* in the square plug. The expanding portion of the plug is then expanded as far as possible, thereby aligning the plug with hole C. In this position, surface *F*

*See Chapter I.

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—M. F. Behar, *Editor*

of the expanding plug should fit into hole *D* without force. The diameter of portion *F* should be sized in accordance with the 40% rule given in connection with the square plug. And it should be borne in mind that the function of this plug is not an inspection for size of the hole in the component part. The determination of the size of this hole should be made with plug or other standard type gages without reference to position or alignment.

(3) The position and alignment of shoulder E with the center-line of bores B and C.

This alignment is accomplished by means of two flat sliding pins, *H* and *I*, in the fixture gage. These pins are accurately positioned with respect to alignment from the hole *G* in the square plug which determines the center-line of holes *C* and *D*. These pins are flat and represent the maximum and minimum distances from the center-line of *C* and *D*. It should be noted that in this case, inasmuch as hole *G* represents definitely the center-line of *C* and *D*, and the square plug is in a definite position within the fixture, a definite distance is in this case maintained for purposes of inspection. The distances from the center-line of the hole *H* to the square pins are dimensioned directly to the component distances rather than based upon the system used for the dimensioning of the square plug.

This gage then accomplishes the inspection of the three conditions required of it. Other special or fixture gages must be designed in the same way, that is, to break down the whole gaging problem into a plurality of simple gaging problems, each of which can be solved by some simple means, and then to assemble these gages into a single fixture to inspect on a functional basis under conditions paralleling final functioning as closely as possible.

With respect to the incorporation of particular types of simpler gages into a fixture gage—a word of advice and a word of caution. Although a flush pin type was not used in the fixture we discussed, flush pins have been found quite adaptable to fixture type gages. The use of springs is not recommended because they usually are not dependable and they should not be used where they will enter into measurement.

Concentricity Gages

Concentricity gages as a class are identified with position and alignment determinations. Some of the simpler prob-

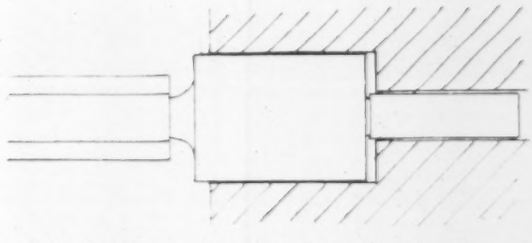

Fig. 5. Cylindrical Concentricity Plug shown inspecting component part (shaded) to determine that the two holes are concentric within the limits of tolerance specified.

lems are solved with fixed gages. One of these is shown in Fig. 5, where only one alignment is involved. Where such a fixed type gage is used, its design is governed by the 40% rule as discussed earlier in this chapter. The great majority of concentricity determinations are made with in-

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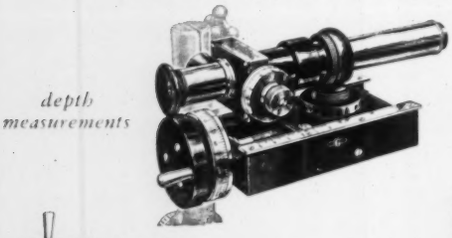

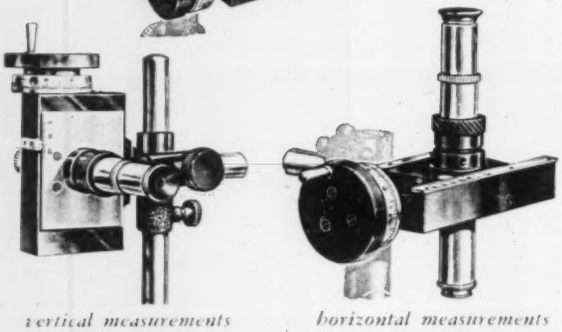

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dicating type gages. One of these is shown in use in [illegible]. In this gage, the reference surface (with which the [illegible] let diameter must be concentric) is the pitch diame[illegible] of the nose thread—which in previous machining oper[illegible]ons has been established as concentric with the body [illegible] the shell. The arm which carries the indicator is rot[illegible]ably fitted to a cylindrical surface which is an extension [illegible] the male thread screwed into the nose thread of the sh[illegible]. It should be noted that the "runout" shown on the d[illegible] is

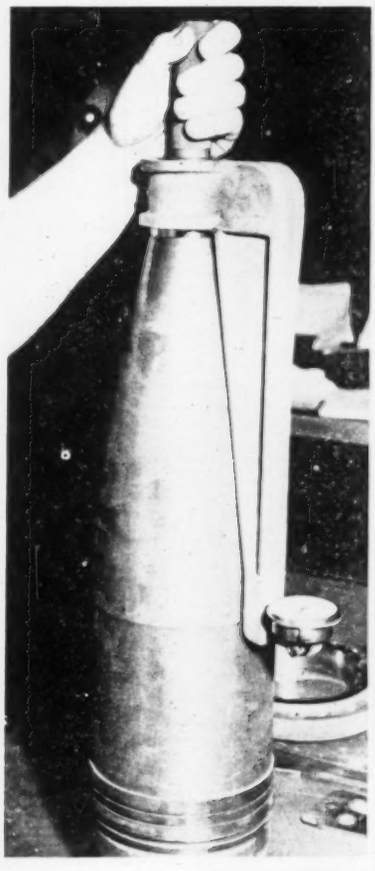


Fig. 6. Concentricity Gage for determining concentricity of the pitch diameter of the nose thread and the bourrelet of the shell. The reading on the dial, as the arm is rotated, is twice the eccentricity of bourrelet with the thread. (U. S. Army photograph.)

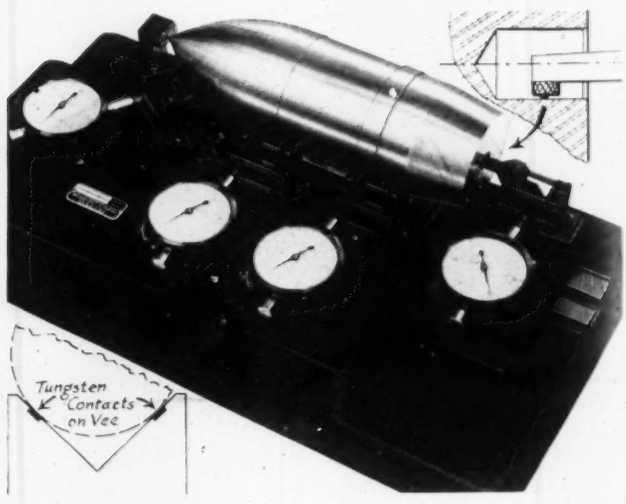


Fig. 7. A shell is here being inspected to determine relative concentricity of diameters along the outside of the shell.

...e actual eccentricity of an outside diameter from ...er line of the shell.

... indicating type concentricity gages, however, are ...nly used for the inspection of more than one align- ...determination at a time. Such a gage is shown in ... The shell seen in this figure is rotated on four ...en bearing surfaces. The indicators, positioned along ...utside and in the cavity at the base, determine the ...at" of the diameter at these points.

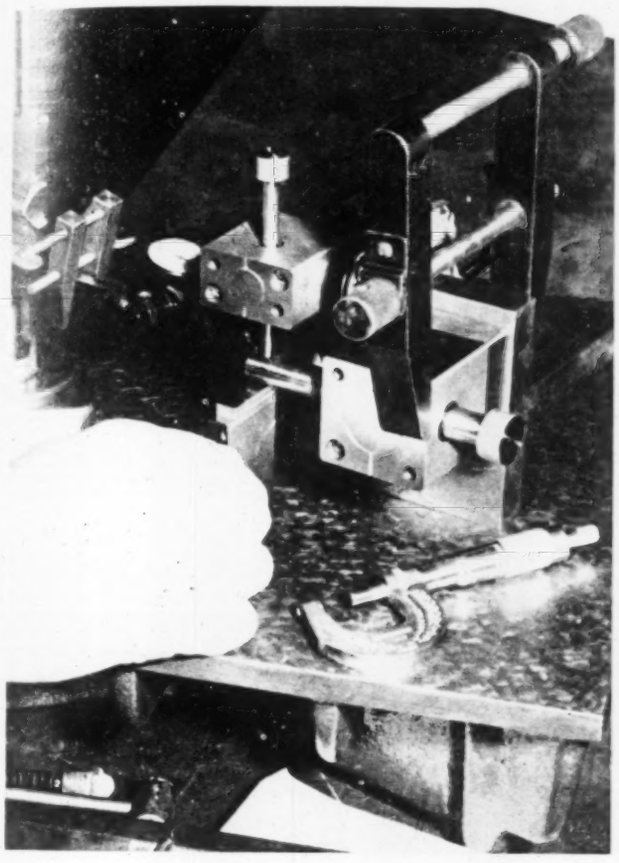


Fig. 8. Inspecting a rather complicated Fixture Gage (for a Point Detonating Fuze). Note the use of flush pin gages. The fixture gage is so designed that when the pins are inserted in the component the relative positions of the center lines will be shown by the flush pin "steps.

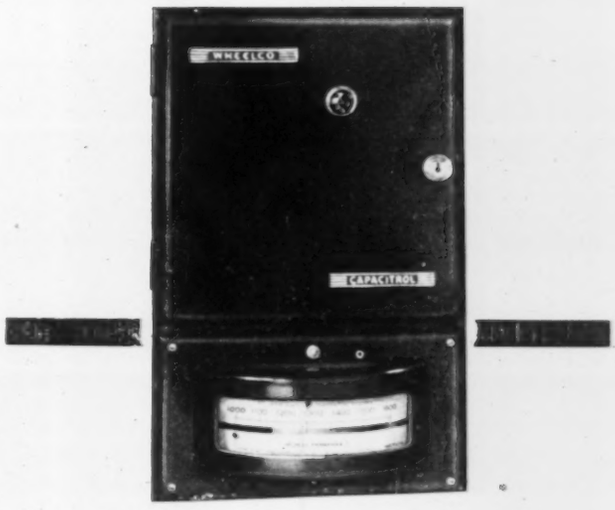
As noted in previous chapters, indicators are frequently employed in size determinations where speed is required and where mastering is simple and easily accomplished. It is in concentricity determinations, however, that the indicator really comes into its own. The indicator is essentially a comparator. Note that the indicator compares the center-line of the shell in one position with the center-line in another position, indicating the *variation* from the center-line to the outside in different positions, but not the actual distances.

Inspection

Fixture Gages

If a fixture type gage is an assembly of simpler type gages, it follows that the inspection of the fixture gage presents the same problems as the inspection of a number of simpler type gages. But, in addition to the inspection of the various parts of the gage, the gage must also be inspected as an assembly—which means that the relative positions and alignments of the simpler parts must be checked in the assembly.

The inspection of the parts which are simpler types of gages will entail the same inspection problems as have been outlined in the previous chapters. These gages should first



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be checked for size without reference to the assembly itself. The fixture gage may be disassembled when it is impossible to perform these inspections otherwise, but it should not be disassembled for inspection purposes as a matter of routine. Fixture gages are, of course, built in such a manner that disassembly and assembly should not alter their functioning.

The inspection of the gage as an assembly will almost always entail surface-plate work. Surface-plate practice as outlined in the preceding chapter should be used, and again the gage should be approached from the standpoint of the inspection of the several phases.

The portion of the gage to check "(1) The alignment of the bore A with the square hole B" consists of the mandrel and the square plug as previously noted. It is necessary to determine first the center-line of the expanding mandrel. This may be done by relaxing the split ring, setting the fixture on a surface plate, and then indicating the ring level. Knowing the diameter of the ring (it can be measured), the exact center-line is determined. The top 1.500" surface of the square plug should then also be indicated level. This may entail perhaps some shimming of the base since it need not be a parallel plane. The split ring will again have to be indicated level and its center-line once more determined. The center-line of the expanding mandrel is now parallel to the top and bottom planes of the square plug. Their relative positions may now be measured. A precision square may be used to determine that the center-line of the expanding mandrel is perpendicular to the sides of the plug, and of course the square plug should be inspected to determine that its sides are normal. In this manner it has been determined that the expanding mandrel and the square plug are positioned correctly.

The other two alignments involved should be considered similarly; and the inspection set-ups to meet the specific cases will suggest themselves.

Fig. 8 shows the inspection of a fixture type gage. In this case, instead of indicating the pin in the foreground level, gage blocks are inserted under the pin and the gage adjusted until the same set of blocks may be slid under the pin at any point along its length with the same "feel."

Inspection of Concentricity Gages

Indicating concentricity gages invariably connote rotation either of the gage around the component part as in Fig. 6 or of the part within the gage as in Fig. 7. The only important consideration in inspecting this particular type of gage is that the center-line around which either the part or the gage is rotated should remain constant throughout the rotation. In Fig. 6, for instance, it is necessary that the bearing surface of the arm and the mating bearing surface of the plug be absolutely round. In Fig. 7, if roller or ball bearings are used (as they often are in place of tungsten points) these bearings should not be measurably out of round and they should run true.

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Vol. I, No. 5 GUEST EDITOR: C. H. SMITH October 1942

Skill Training for Aircraft Instrument Technicians

Editorial by **C. H. SMITH**, *Guest Editor*
President, Chicago School of Aircraft Instruments

IN the rush and hurry of training the thousands of aircraft instrument mechanics needed to help maintain our war effort, one important factor seems to be overlooked all too often—the fact that the work of the instrument technician is, after all, a highly skilled function. Like the toolmaker and the watchmaker, the instrument mechanic must be a master craftsman. And, like the toolmaker and the watchmaker, he cannot learn his craft out of books.

True, instrument work is a combination of many skills, and the worth-while instrument man must have his "book learnin'" too. He must be taught what the instrument is, where it is used, and how it operates. He must be taught, also, the principles of instrument calibration and repair. But, unless he has acquired the proper manual skills and techniques, all of his knowledge will be of no real practical value to him as an instrument mechanic.

Moreover, the instrument man of today must be a more competent and resourceful instrument technician than ever before, because, in the majority of cases, he is working under conditions where he does not have at his disposal all of the latest types of tools and test equipment, and often does not have access to a complete stock of repair parts and supplies. Today, the instrument mechanic must be able to overhaul his instrument, using a minimum number of tools and a maximum amount of skill. Today, he often must make his own repair parts, because the desirable replacement parts cannot be obtained without great delay. Particularly is this true of the instrument man in the Army and Navy, who may be called upon to do a complete overhaul job in some overseas air base.

Clifford H. Smith, President of the Chicago School of Aircraft Instruments, has literally spent his entire career in industrial training work. At eighteen, after a year at Purdue University, he joined his father at the Industrial Training Institute in Chicago to take charge of that school's Student Welfare Division. During the 18 years that have elapsed since then, he has served as Vice-president of the Industrial Training Institute, in charge of the training of more than 400,000 students in different industrial fields. During that time he also managed to graduate from Northwestern University School of Commerce. When the Industrial Training Institute took over the Chicago School of Aircraft Instruments in January, 1942, Mr. Smith was made President of the C.S.A.I.; and it is he who has been responsible for its amazingly rapid growth to the large and well-equipped school that it is today. His own eighteen years of previous experience in industrial training work, coupled with the accumulated resources of the old-established Industrial Training Institute, bring to the aircraft instrument field a combination that is perhaps unique and certainly fortunate.

Yet, time does not permit putting the future instrument mechanic through the normal type of an apprentice training. The months that should be devoted to teaching the instrument man the use of hand tools and bench tools cannot be spared. His training today must be short and snappy, and yet complete.

This necessity has led to the development of a unique skill training program which is now in operation at the Chicago School of Aircraft Instruments. Here, newly enrolled students, civilians and enlisted men alike, are put through an intensive primary skill training before being permitted to practice on actual aircraft instruments. This so-called primary shop training is intended to, and does, teach the would-be instrument mechanic all of the basic skills that he must possess to do real instrument work. He is taught the use of small hand tools, taught to operate bench lathes and jewelers' lathes, taught how to make his own special tools, how to stone and polish pivots, and many

Fig. 1. Beginners in one of the primary shops learning to operate bench lathes and jewelers' lathes as part of their skill training. Students in the background are making small hand tools.

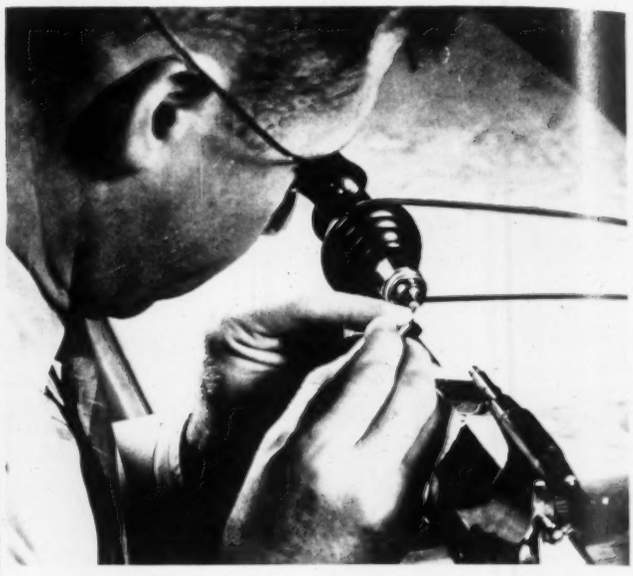

Fig. 2. This student is turning a 0.006" pivot on a jeweler's lathe—one of the primary shop projects that teaches the embryo instrument man accuracy and the use of precision instruments.

other operations such as broaching, peening, hair-spring straightening, soldering, and so on. The whole process only takes from 100 to 120 hours of actual school work—because it is accomplished through the means of shop projects carefully designed to give each student ample practice on each necessary skill.

Students begin their training by making specialized tools that they will use throughout the remainder of their instrument training and in subsequent actual instrument overhaul work. (See Figs. 1, 2 and 3.) Air Force students in the Mechanical Instrument School make such special tools as an offset screw driver, pointer lifting tool, pointer staking-on tool, etc. Students in the Electrical Instrument School make special Weston assembly wrenches, electrical instrument movement assembly stands, special screw drivers, etc. Those students who are specializing on gyroscopic instruments make such different tools as ball-bearing polishing tools, special pivot and race lapping tools, special wrenches, etc. Students in the school's Civilian Classes make all of these tools, since they must work on all three types of instruments.

Each student then builds a specially-designed instrument mechanism from raw materials. (See Figs. 4 and 5.) This mechanism, when finished, demonstrates clearly the general principles of operation of pressure type instruments and gives the student an opportunity to learn the many specialized skills required of the instrument maker. He must, for example, lay out all parts on raw stock, cut, file and finish to shape. He learns drilling and tapping and the use of sensitive drill presses for the handling of very small tools. He must turn numerous parts on both the bench lathe and the jeweler's lathe. He must make his own pivots and bearing surfaces, his own hand staffs, wind his own hair-springs and, in general, go through the entire range of operations that he must later be able to do almost as a matter of habit.

Above everything else, the student is taught to work accurately to close tolerances. One of the projects requires turning a pivot with a diameter of 0.006". (See Fig. 2.) Many of the tools must be made to one thousandth of an inch accuracy. Long before the student has completed his primary shop training, he has learned to think in terms of thousandths of an inch and ten thousandths of an inch. Micrometers, depth gages and other precision instruments are no longer mysteries to this student.

With this training behind him, the student can now enter his classes on actual aircraft instrument overhaul, with

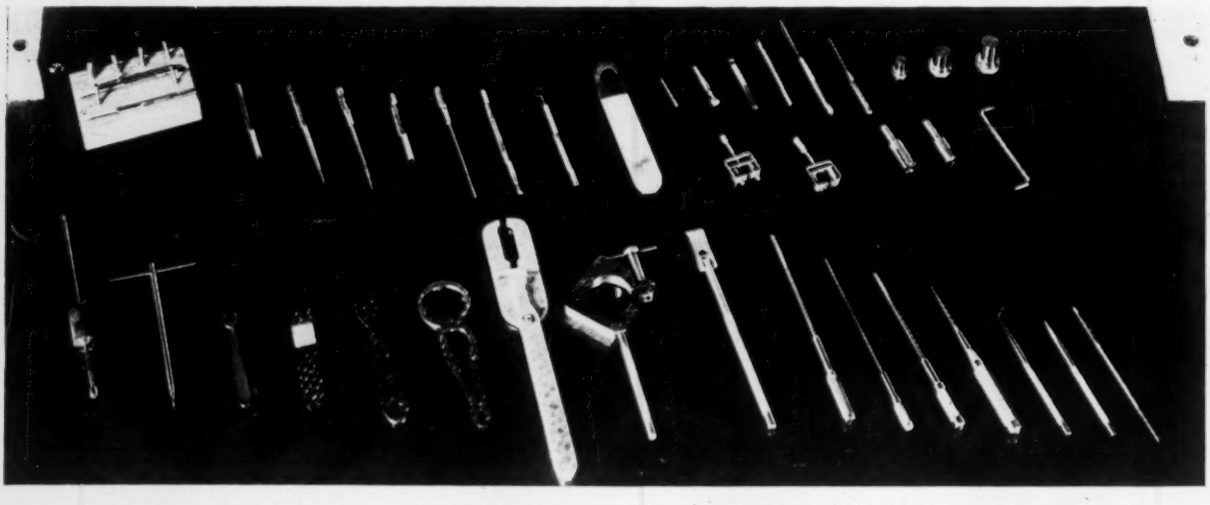

Fig. 3. Some of the hand tools made by one class of Army Air Force students during their first two weeks of work at the Chicago School of Aircraft Instruments. Most of the men in this class had had no previous mechanical experience or training.

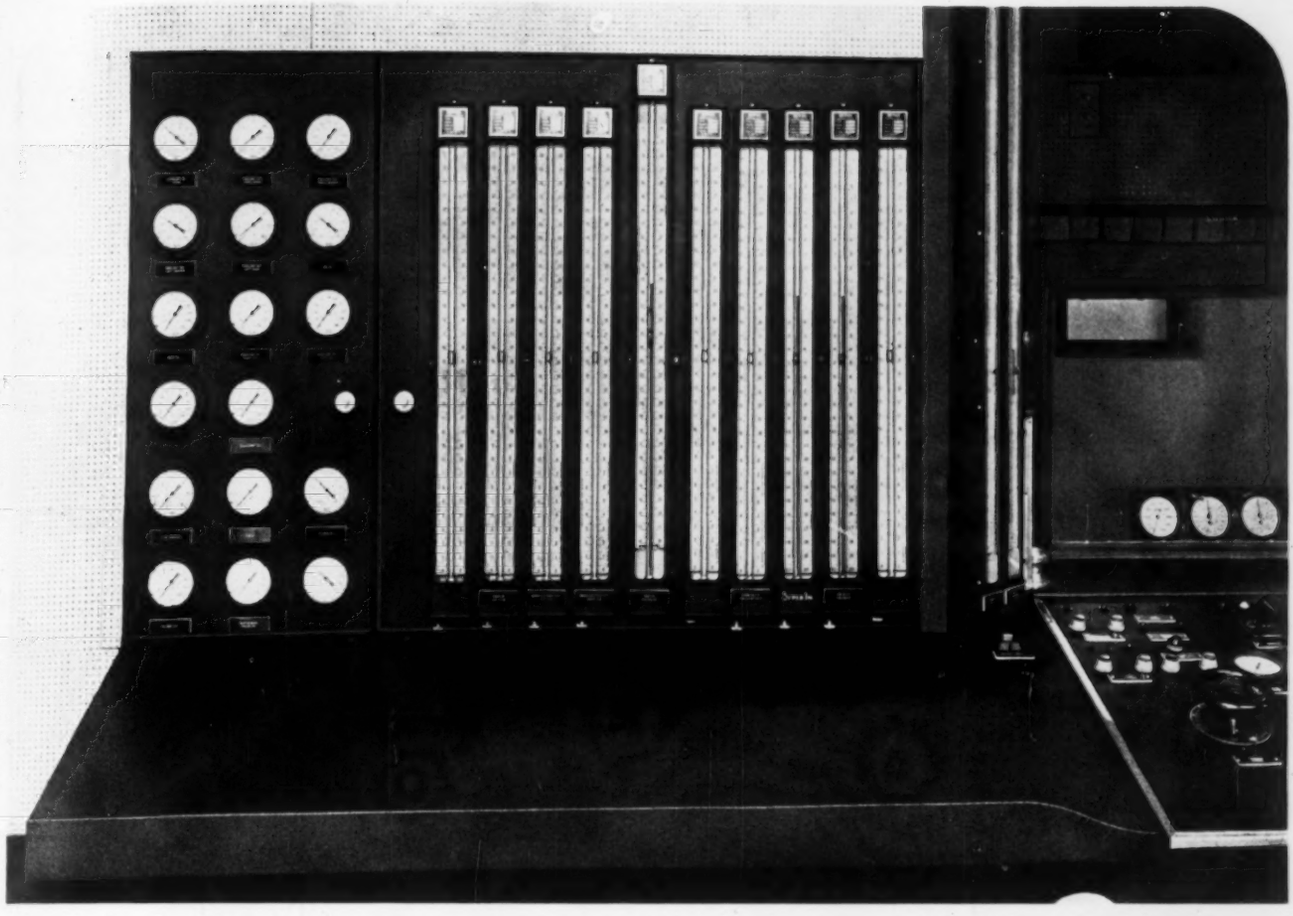

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Fig. 4. Students assembling practice instrument mechanisms. These mechanisms, when finished, are used in demonstrating calibration principles utilized in many pressure instruments.

Fig. 5. Student nearing the end of his skill training, assembles an instrument mechanism, every piece of which he has made from raw stock.

confidence in his ability to handle any of the mechanical operations that he may be called upon to do. Now he can, indeed, devote all of his thoughts and attention to the instruments, themselves, and to the learning of the overhaul and calibration processes. (See Figs. 6 and 7.) Now, too, he can learn with many times the rapidity that he would if he had to acquire his manual skills and techniques as he went along. In the opinion of the Technical Staff of the Chicago School of Aircraft Instruments, the development of the preliminary shop trainings has speeded up the entire learning process for an instrument mechanic at least 25%, and possibly more. This has been particularly true in the Army Air Force School where most students have had little or no previous experience of a similar kind before being assigned to instrument work.

Another vitally important benefit of this intensive skill training lies in the fact that it makes the graduate student infinitely more resourceful; hence, it materially increases his value as a general all-around instrument mechanic. He can, for example, re-pivot instrument parts, if they cannot be purchased from the manufacturer and, thus, maintain in service instruments that would otherwise be beyond repair. If no new hair-spring is available to replace the one that has been damaged, he can fix the old one and make it work. He can always do a better job, of course, with proper test equipment and proper tools, and a supply of replacement parts to draw upon. But, if those items are not available, many times he will be able to do the job without them and make the instrument function properly.

Fig. 6. Instrument mechanic assembling a sensitive altimeter prior to calibration.

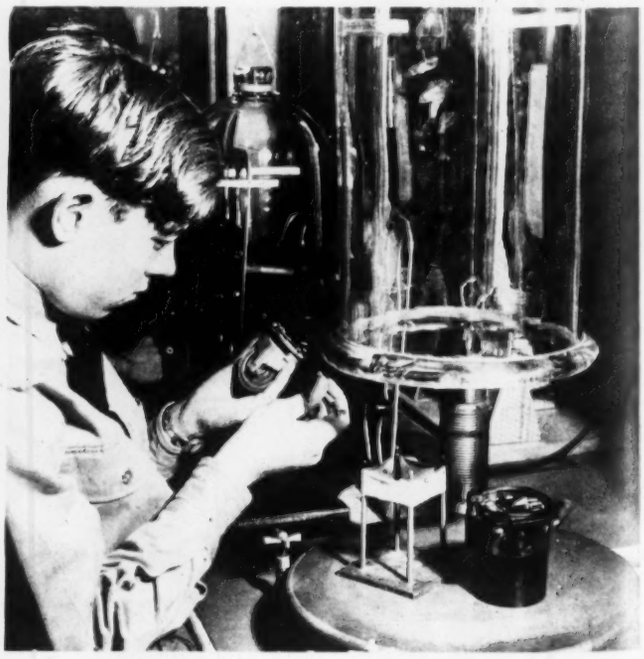

Fig. 7. Instrument mechanic making a delicate adjustment on a sensitive altimeter.

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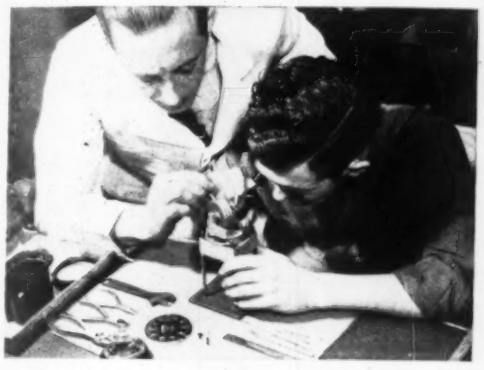

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Calibrating Pressure-actuated Instruments by Means of Graphs

By ELSWORTH KEITH, Jr.
Director of Training, Chicago School of Aircraft Instruments

TIME is such an important factor these days, that we have had to eliminate all lost motion in teaching aircraft instrument overhaul and calibration at the Chicago School of Aircraft Instruments. On top of that, we've had to turn out graduates who were ready to step into responsible positions *immediately*, and without the usual six or eight months of apprentice experience that such a graduate would normally receive before being assigned to actual instrument overhaul work. Consequently, we've had to develop some new methods and refine many older ones.

The calibration of pressure-operated instruments, such as manifold pressure gages, altimeters, airspeed indicators and rate-of-climb indicators, has always been a problem to the inexperienced instrument mechanic, and to many an old-timer as well. In fact, there are far too few experienced instrument technicians who can calibrate such instruments accurately. Yet, the process of calibration is not a difficult one, if the man who is doing it knows WHAT he is trying to do.

It isn't half so much a matter of technical skill as it is a problem in diagnosis.

Let us take for example a sensitive altimeter that has just been completely overhauled by a skilled instrument mechanic—or by a student, for that matter. Let us say that it has been carefully inspected by the shop foreman, or, in the case of a student, by his instructor. The foreman knows that all pivots have been carefully inspected and refinished; all jewels cleaned; all gears adjusted to proper mesh; and everything else done to put the instrument in perfect working order. Now the instrument must be calibrated—made to read correctly at all altitudes within its range.

The mechanic takes the instrument to the test bench bell jar to find out how it will read in comparison with a master altimeter. He takes a reading at the pressure corresponding to an altitude of 1000 feet, another at 2000 feet, and others at intervals of 1000 feet to the limit of this particular instrument's range. Then he looks at the figures to see what they show, and begins to scratch his head.

Our man knows all of the rules for calibration. He has been told that—

> If the instrument runs slow near the top of its range, move the diaphragm out, and if it runs slow throughout the entire range, move the rocking-shaft lever arm in.

So, he begins to make adjustments. Perhaps he adjusts the rocking-shaft lever arm, first. Then, he takes a few more readings and finds that at certain altitudes his instrument now reads correctly, but at other altitudes it is just as far off as before—perhaps farther. So he makes other adjustments and takes more readings. Some of the adjustments seem to help; others make the instrument worse. He makes still more adjustments and, finally, in despair, consults the foreman or instructor about the problem.

Let's stop here for a moment. This man, who had previously been able to *see* the results of his work as he went along—see the excellent condition of all the various mechanism parts after he fixed them—has suddenly lost his ability to *see* what he was doing. Instead of having before him a clear picture that he can see and understand, he now has nothing but a confused jumble of figures that only seem to get more confusing as he goes along. Soon, he even begins to lose faith in the excellent work he did in overhauling the instrument, because "the darned thing" just won't calibrate. Finally, he lets "good enough" be his goal, and loses all of the pride and satisfaction which he should get from a good job well done.

But—this man should have seen what he was doing, if he had only known how. The instrument man who has been trained to use graphs in calibrating pressure instruments, and who has been taught how to interpret them, always has a clear and complete picture of his work, and will know exactly what to do at any given time in order to calibrate his instrument correctly. Moreover, once a man has mastered the ability to interpret a graph as being indicative of certain definite corrective adjustments, he immediately becomes an expert at calibration, and can handle any calibration problem on any type of pressure-operated instrument.

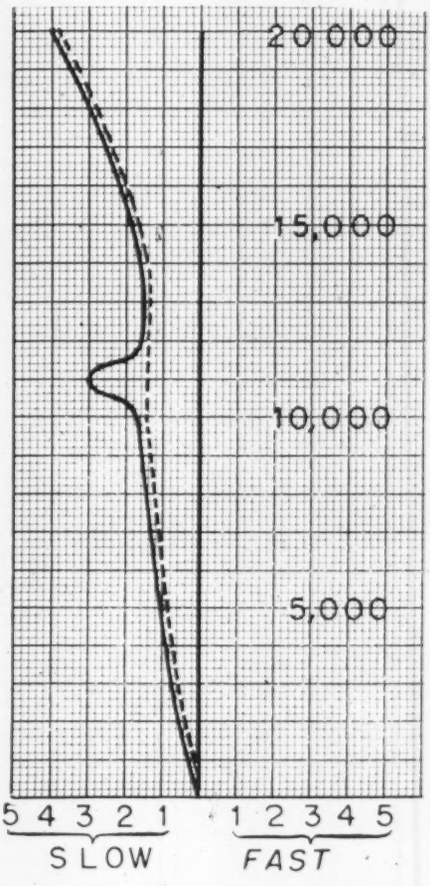

Fig. 1

For purposes of illustration, let's follow one of our students as he calibrates a sensitive altimeter that he has just finished overhauling to the satisfaction and approval of his instructor.

First, he makes an ordinary "T" graph of the readings of the master altimeter from 0 altitude to 20,000 feet. Then he puts his own instrument in the bell jar and records on the graph its readings at 1000-foot intervals. When he gets done, he finds that he has a curve such as that shown by the solid line in Fig. 1 (the straight vertical line is the reading of the master instrument).

Our student now studies the picture that is before him. He sees immediately that his instrument is generally slow. But, he also sees two other important things. First, he sees a sudden increase and decrease in the error between 10,000 feet and 12,000 feet, as indicated by the "bump" in the graph line. Second, he sees that at the extreme top of the instrument range, the reading becomes slow at a noticeably increasing rate.

That "bump" at the 10,000-foot level can mean only one

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Elsworth Keith, Jr., Director of Training at the Chicago School of Aircraft Instruments, is a typical product of his time. A young man, only twenty-eight years of age, Mr. Keith was selected as Director of Training for this school because of his unusual abilities as an Aircraft Instrument Technician and because of his natural aptitude for educational work. Today, in charge of what probably is the largest school of its kind in the world, Mr. Keith is doing a noteworthy job—a job that many a seasoned professional educator could envy in more ways than one. To no small degree, the Chicago School of Aircraft Instruments is a product of this brilliant young man's efforts, and the whole aircraft instrument field owes him a vote of thanks for his accomplishments.

—CLIFFORD H. SMITH

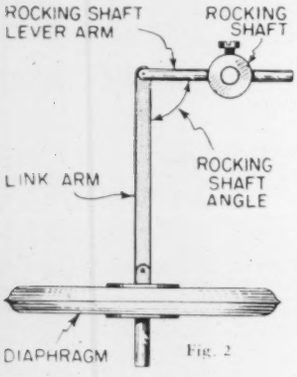


Fig. 2

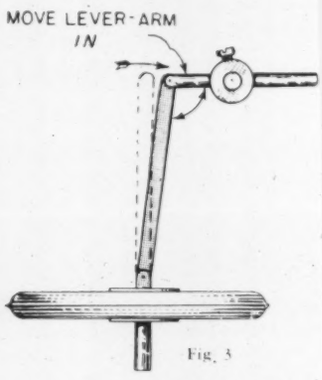


Fig. 3

thing—friction in the instrument mechanism. (It could also mean that the diaphragm unit is damaged, but, in this particular case the diaphragm unit is known to be o.k.) The first thing to do, then, is to get rid of that friction, because, until that is accomplished, he can't hope to get anywhere with his calibration. He, therefore, takes his instrument back to the work bench, locates the source of friction, and removes it. Now he charts the instrument reading again, and gets a curve such as the dotted line in Fig. 1, showing a generally slow condition, but without any "bumps."

He knows that when an instrument reads generally slow throughout its entire range, as this one does, he must make an adjustment in the mechanism. Suppose that the relationships between the diaphragm, rocking-shaft, rocking-shaft lever arm, and the link-arm are as pictured in Fig. 2. Any student who knows how to interpret graphs now knows that by moving the rocking-shaft lever arm in toward the rocking-shaft, as indicated in Fig. 3, a "slow" instrument will be "speeded up." Having made such an adjustment, he again takes readings at 1000-foot intervals and graphs them, producing a curve such as the solid line in Fig. 4.

Our man has made progress. He now has his instrument reading correctly from 0 altitude to 16,000 feet. However, above 16,000 feet, the calibration is still poor, and the sudden curve to a slow indication can mean only one thing—a misadjustment of the rocking-shaft angle.

Again, the student goes back to the work bench, this time to make a rocking-shaft angle correction by moving the diaphragm as shown in Fig. 5. Once more he runs the instrument through its test. This time he gets a result as is shown by the dotted line in Fig. 4. Now the instrument is a little fast, which he expected might be the result of his last

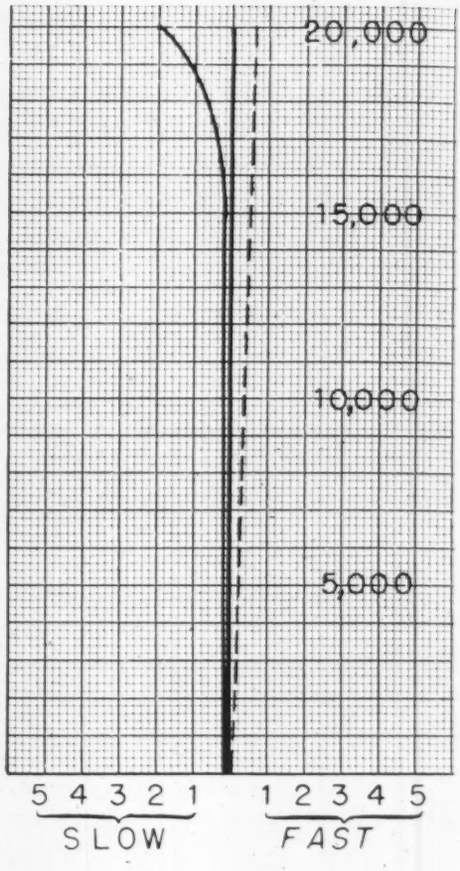


Fig. 4

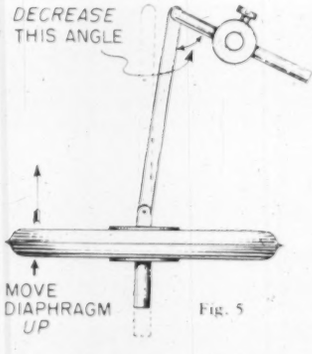


Fig. 5

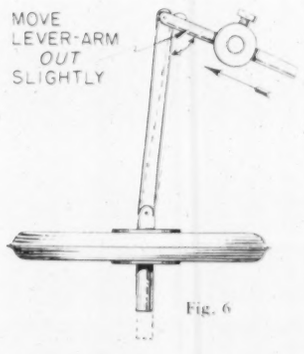
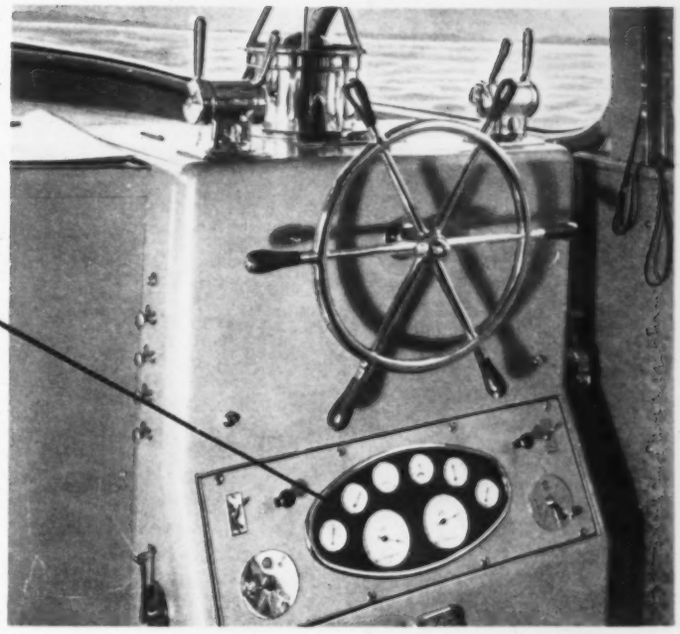


Fig. 6

adjustment. But, all "bumps" and curves have now been removed, and our student knows that the next adjustment will finish the job. This simple adjustment is shown in Fig. 6, where the rocking-shaft lever arm is moved slightly away from the rocking-shaft, thus accomplishing perfect calibration.

The entire calibration process of pressure-actuated instruments is a simple step-by-step elimination of the individual errors which cause the instrument to read incorrectly. To perform such a calibration in the least possible time, in fact, to do it all, requires that the mechanic be able to diagnose the faults that are inherent in the instrument, and that he know which are to be removed first and which to leave until later. Graphs, alone, will not supply the answer. They merely furnish the picture, which the mechanic must be able to read. However, once he has been taught to read the graph and to understand its indications, he knows at every step of the way, exactly what to do next. There can be no lost motion, no retracing of steps, and, to the properly trained man, no result except proper calibration.

Today, all students at the Chicago School of Aircraft Instruments, both Civilians and Army Air Force enlistmen, are taught to make and read graphs before they ever begin to work on instruments, themselves. Calibration, therefore, holds no terrors for them.



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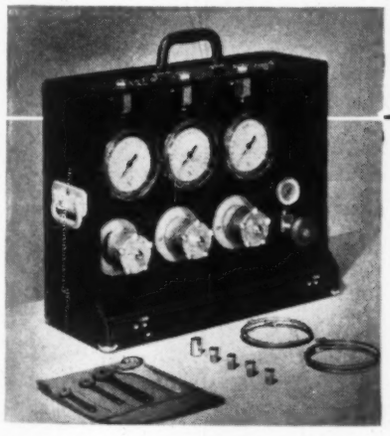

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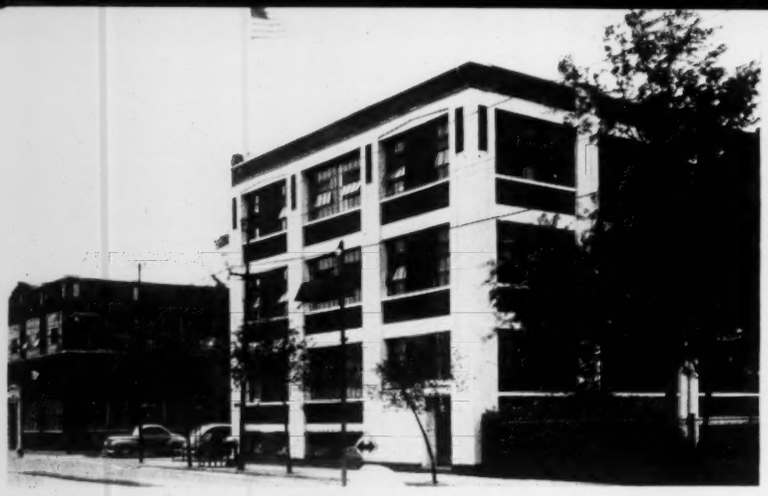

Fig. 1. The building on the left is the present home of the Chicago School of Aircraft Instruments. At right, former Administration Building of Industrial Training Institute, now an Army barracks.

Fig. 2. A part of the Army Air Forces School, handling 180 men at a time in two eight-hour shifts. A similar Civilian school handles 315 men in three six-hour shifts.

Mass Training of Instrument Mechanics to Meet War Needs

By C. H. SMITH

President, Chicago School of Aircraft Instruments

WHEN Japanese planes appeared over Pearl Harbor last December 7, it is doubtful if there were more than two hundred specially trained aircraft instrument technicians in all the United States. Most of these were concentrated in the instrument repair shops of our large airlines, for, after all, only our commercial airlines and a few of our military planes used anything but the simpler type of aircraft instruments. Then, suddenly, the aviation industry was called upon to produce 185,000 military airplanes in less than two years—every such plane equipped with all of the latest type of aircraft instruments.

Before that time, only a few hundred aircraft instrument technicians had been needed in this country. Suddenly, thousands of them were needed. And, every such man had to have months of training to be of any value.

To provide all of these trained instrument mechanics, there were only two or three relatively small schools in the whole country. New ones could not be established, because the delicate test equipment and the precision tools needed, as well as the necessary practice instruments for student work, literally couldn't be procured for love nor money. Such test equipment, tools and instruments as were available were needed by fighting planes and instrument men on fighting fronts. Yet, these thousands of instrument mechanics had to be trained, and it became the task of the few schools that existed at the beginning of 1942 to find some way of doing the job.

Typical of the job done by America's private aircraft instrument schools, is the story of what one such school has accomplished since January 15, 1942.

On that date the Chicago School of Aircraft Instruments, in its quarters on Chicago's Municipal Airport, had the necessary equipment, space, and staff for training approximately thirty instrument mechanics at one time. As of August 15, exactly eight months later, this school has an Army Air Forces School set up to handle 360 enlisted men at one time, and a Civilian School with a capacity of 315 civilians at one time. This total of 675 students in one school would not be a great number in an ordinary vocational school, nor in a modern radio school. In fact, a group of 675 students is a small number for any experienced educational institution to handle. But, in an aircraft instrument school, 675 men is a group of colossal proportions.

In a well-equipped instrument school, every student must have at his disposal, for actual practice work, at least $10,000 worth of the latest types of aircraft instruments. He must have available for his use at least $15,000 worth of precision test equipment and tools. To expand this small school from a capacity of thirty men to a capacity of 675 men constituted a procurement problem of staggering proportions. Moreover, you can't teach instrument mechanics without instructors to do the job. Great as has been the

(Continued on Page 439)

Fig. 3. A typical section of the Civilian School, showing a class of fifteen men working in the Pressure Department under the supervision of an Instructor.

Fig. 4. Pressure Department test benches in the Civilian School, where students calibrate all types of pressure instruments.

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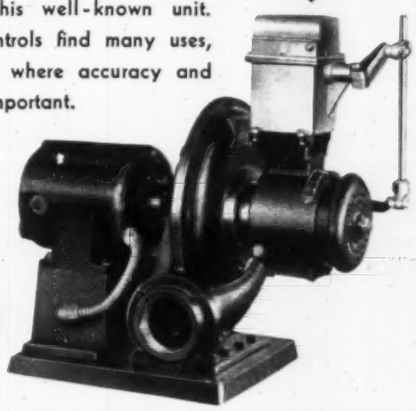

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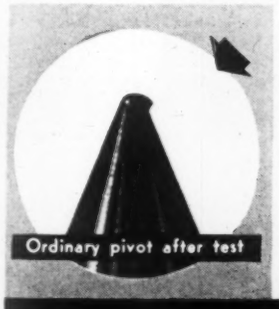

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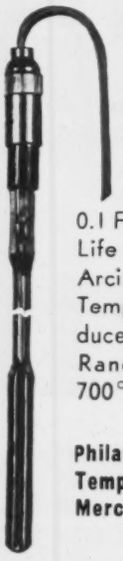

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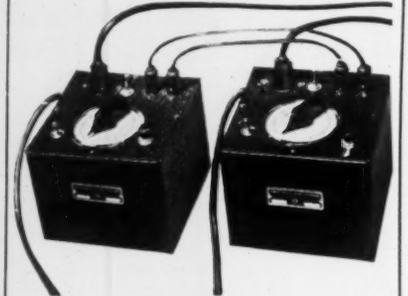

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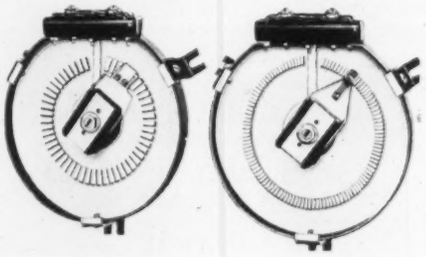
Field Rheostats

New series of pressed steel field rheostats with solid rectangular contacts are said to provide a finer degree of control, smoother operation, and certain economies where interpolating rheostats would otherwise be required. Rectangular contacts are available in small and large sizes. Small rectangular contacts can be furnished on 13" or smaller



rheostats. Large rectangular contacts can be furnished on 8" or larger rheostats. Rheostats with rectangular contacts can be furnished with complete enclosures, fittings for conduit connections, motor drives and with accessories for floor, back-of-board, and concentric mounting. Fixed and adjustable stops to protect control equipment can be provided.—*Ward Leonard Electric Co., Mount Vernon, N. Y.*

Nine-step Ayrton Shunt for Galvanometers

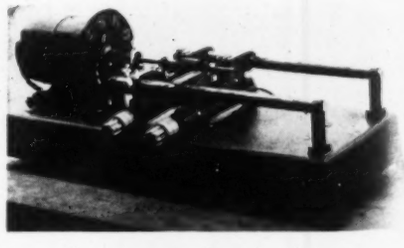
New Fisher Ayrton Shunt increases the range of a laboratory galvanometer many fold and obviates the need for makeshift electrical wiring. With it, a single galvanometer can be used to measure current in steps of 1, 2, 5, 10, 50, 100, 200 or 500 times its normal range. These nine steps are obviously more useful than the 1, 10, 100, 1000 factors of ordinary Ayrton shunts. New shunt makes it possible to have galvanometer range only slightly greater than maximum current being measured at any time, hence maximal deflection for slight changes in current. This enables closer reading and, therefore, more accurate determinations. Fisher Ayrton Shunt has a resistance of 2,000 ohms which is correct for use with Fisher "Model F" mirror galvanometer. (When other galvanometers are to be used, an inexpensive resistance of proper value will adapt new shunt.) The complete shunt is about four inches square and 2" deep.—*Fisher Scientific Co., 711 Forbes St., Pittsburgh, Pa.*

"Eight-in-one" Manometer

New "Model A-338" is a well type direct-reading manometer specially designed for testing aircraft instruments. It has a flexible scale arrangement so that this single instrument can be used to test all aircraft instruments operating on the pressure or vacuum principle. It is said to have extensive application in laboratory and field servicing for checking calibration to determine functioning of these classes of instruments. It incorporates an eight-sided scale selector, permitting the selection of proper scale for particular aircraft instrument being checked. All scales are adjustable to suit barometric conditions in any specific locality and are direct-reading in miles per hour, knots, pounds, inches, millimeters, etc. The range is from 0 to 61 inches of mercury or water. An integral return well prevents loss of indicating fluid.—*The Meriam Co., 1971 West 112th St., Cleveland, Ohio.*

Bench Type Dynamic Balancing Machine

New "Model 335 Dy-Namic" balancing machine is most recent addition to maker's line of industrial dynamic balancing machines ranging from 4 oz. to 1000 lbs. in capacities. Its limits for rotating-part weights are approx. 6 oz. and approx. 20 lbs. It has been especially designed for extremely accurate determinations on rotating components of precision equipment. It is said to utilize a new balancing principle whereby the position and amount of unbalance are both indicated at the same time, as in the most expensive machines, but permitting such results to be obtained from an easily-operated low-cost machine.—*Reed Mfg. Co., Rock Island, Ill.*



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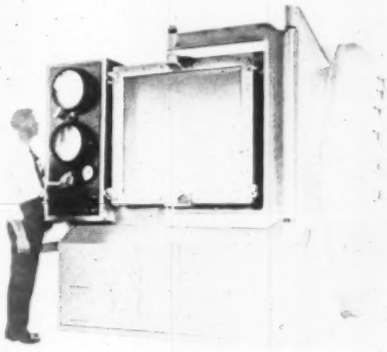

variations are controllable throughout their ranges. Freon-12 is used as the refrigerant. Refrigeration effect, or heat acceptance from the chamber, is by forced convection through coils designed for low-temperature work. Each coil will accept a minimum of 200 B.t.u. per degree at −75°F. and 3" mercury pressure. Humidity control is from 25% to 95% relative at all temperatures above +40°F., or at a fixed bottom temperature of striking the photocell. Circuit comprising photocell and indicating instrument is designed to give linear response. Photocell is said to have unlimited life. Indicating instrument is provided with anti-parallax knife-edge pointer and mirror. Dial carries a scale indicating transmission in percent and a density scale which, in most instances, gives readings directly proportional to concentration. Choice of filter depends upon color of solution under test. Instrument has ample sensitivity for use of highly selective color filters isolating narrow spectral bands. Filters can be interchanged. A constant voltage transformer provides constant light output of lamp even if line voltage fluctuates. — *Photovolt Corp., 95 Madison Ave., New York City.*

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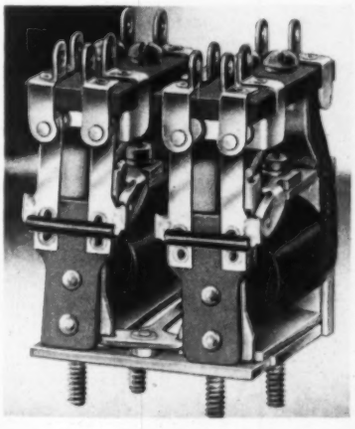

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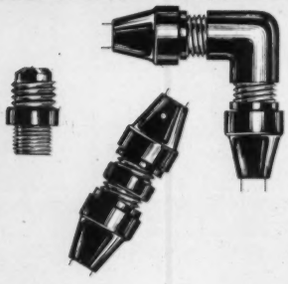

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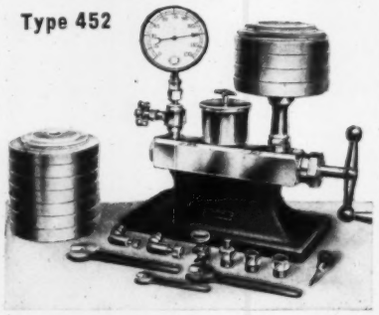
Type 452



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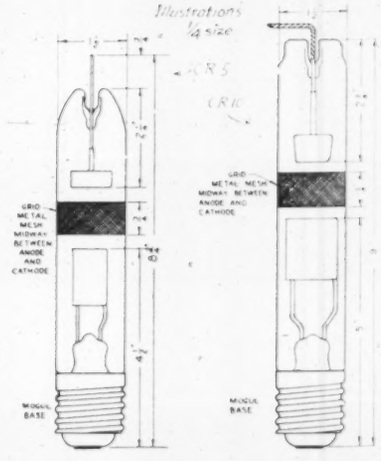
Crest Voltmeter for Ignitio and Corona Voltages

New electronic crest voltmeter is signed to measure ignition voltages of ternal combustion engines; surge volta caused by corona and surface discharges the insulation on such electric equipm

as motors, generators, and cables; and other repeated-impulse voltages up to 30,000 volts. Instrument weighs only 23 lbs., is said to fill the need for a portable crest voltmeter for both laboratory and production testing. Suitable for field measurement such as trouble-shooting and determination of actual operating conditions, it can also be used for testing aircraft engines in flight. It can be used in areas where no electric power is available, since it has a self-contained battery power supply. It can be moved readily to any location for testing purposes—a valuable feature when the equipment to be tested is too large to be moved conveniently. The voltmeter is equipped with an aircraft-instrument movement to provide resistance to vibration. It can be supplied marked and calibrated for any of the following scale ranges: 0-10,000 volts; 0-20,000 volts; 0-30,000 volts.—*General Electric Co., Schnectady, N. Y.*

External-grid-control Industrial Electron Tubes

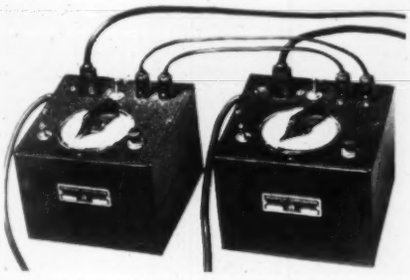
New "CETRON CR-5" and "CETRON CR-10" industrial electron tubes are of the external grid control type. Makers recommend that a ¾" wide band of metal mesh be used for the grid (as in illustrations) although a ¼" metal ribbon or even a couple of turns of No. 14 wire can serve in



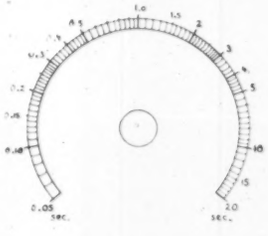
instances. These new tubes are recommended principally for on-and-off operation but in certain cases they may be used in phase shift circuits to give gradual control of current. Objection to latter method is that as temperature of tube increases, grid characteristics of tube tend to drift because current through tube to change. When control change is fairly rapid, however, this effect becomes negligible. Wide line variations, too, may cause current to vary, but this effect will not be present when off-on control is employed. Makers recommend that these tubes be used with phase shift rather than amplitude control. If grid potential is 180° out of phase with plate potential, any voltage exceeding about 30 volts r.m.s. will suffice to give off-and-on operation of the tube with 110-volt plate. Best operation will be secured at a potential of 50 or 60 volts on the grid. Grid power required is extremely small since there is no physical connection with the electron stream of the tube. In fact, these tubes are operable directly with photocells, using the conventional phase shift circuit consisting of a photocell and small capacitor in series.—*Continental Electric Co., Geneva, Ill.*

Electronic Timers

New "Model 900" and "Model 910" Photovolt Electronic Timers close or open circuits for preset intervals; but any number of the "900" can be combined by plug connections (photograph shows two thus connected) without requiring any additional relays or control units, so that an infinite



variety of schedules is made possible. Each timer can take care of several switching operations. Operating principle of both models is capacitor charge and discharge through adjustable resistors, permitting a logarithmic time scale with equal degree of



precision at all points (see cut). Some other features: (1) Immediate automatic resetting.—After completing timing period, it does not take more than 1/60 sec. for timer to be ready for next operation. (2) Powered and unpowered load.—Timer is provided with a load outlet carrying 110 volts and with terminals for opening or closing an external circuit. Powered and unpowered loads can be switched simultaneously. (3) Adjustable for "normally open" and "normally closed."—By changing connections which are easily accessible, both loads can be made to "make" or to "break" during the timing period. (4) Push button and remote control.—Timer can be actuated either by the push button which is provided on the panel or by an external switch such as a foot pedal or a machine-operated switch to be connected to the remote control socket of the timer.—*Photovolt Corp., 95 Madison Ave., New York City.*

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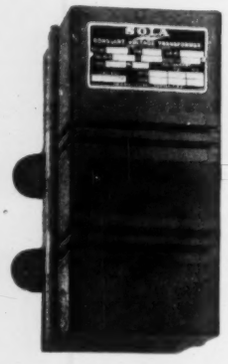

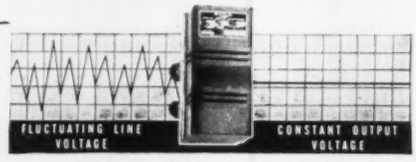

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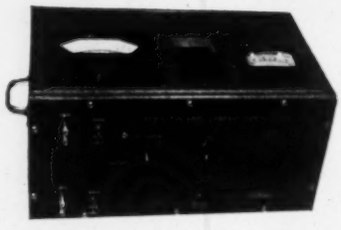

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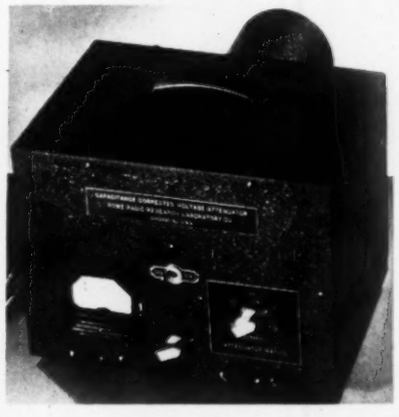
Plastic Gage Handles

Development of new plastic gage handles was prompted by shortage in critical metals. These new Federal Taperlock Gage Handles are said to be accurately made to

the standard dimensions accepted throughout the industry. Plastic being much lighter than metal, this permits a lighter touch and reduces possibility of fatigue from long continued use. New handles are marked with the same lettering stamps used for marking metal handles. They are available in any quantities.—*Federal Tool Corp., 405 N. Leavitt St., Chicago, Ill.*

Attenuator-calibrator for C-r. Oscillograph

New "Type CA211" capacity-corrected attenuator-calibrator for ignition and high-voltage wave-shape or peak voltage determinations consists of two instruments in a single case. Attenuator allows the application of ignition high voltage to a cathode-



ray oscillograph for voltage indication and for viewing wave-shape. Calibrator allows adjustment of the attenuator-oscillograph combination so that the oscillograph screen may be read directly in kilovolts per inch of deflection. The attenuator includes a network of capacitance-corrected resistances said to be arranged in an exclusive design that provides thoroughly satisfactory attenuation over the frequency range of 0 to 50,000 cycles per second. The calibrator components allow accurate voltage calibration so that when used with a matched oscillograph, voltage deflection sensitivities of 1, 1.5, 2.5, 5 and 10 kilovolts per inch are available by the turn of a knob.—*Rowe Radio Research Lab. Co., 4201 Irving Park Blvd., Chicago, Ill.*

Oil and Insulation Testing Set

Improved 35,000-volt oil and insulation testing set can be converted for high-potential tests on a variety of materials and products. It consists of a 2-kva, 35,000-volt liquid-immersed testing transformer; an air-cooled variable-voltage autotransformer; an air circuit breaker for opening circuit after test is completed; an oil-testing receptacle; a push-button station; and a double-range voltmeter for accurate indication of the insulation breakdown voltage. All these parts are mounted as a unit on a three-wheel ball-bearing truck. Oil-testing receptacle contains the test gap and is so mounted on the high-voltage terminals that tilting the receptacle empties the tested oil into a drain pan. The oil-testing receptacle is easily removed to convert the set for

stat[illegible] high-potential tests on such materi[illegible] and equipment as sheet insulation, cable[illegible] small transformers, rubber gloves, small [illegible]otors and generators, circuit breakers, [illegible] materials, bushings and insulators. Positive control is assured through push-button[illegible] which must be held down throughout the test. Red signal lamp warns operator

when transformer is energized. Variable-voltage autotransformer provides for easy control of the output voltage and its handle is equipped with a graduated dial for approximate indication of test voltage if sample being tested breaks down before voltage is read. Testing set is provided with a 15-foot flexible cord and plug for connection to any 115-volt or 230-volt a-c outlet.—*Transformer Div., General Electric Co., Schenectady, N. Y.*

Oscillograph Pre-amplifier

New "Type PA114 Pre-Amplifier" was designed especially for use with the Rowe Radio "D5RR9" and DuMont "175-A" Oscillographs (described elsewhere in this issue) but it can readily be employed in front of any other oscillograph or amplifier. It provides additional amplification so that

when used with the "D5RR9" Oscillograph the total amplification is as great as can be practicably employed. The frequency response of the amplifier is flat from less than one cycle per second to well over 50,000 c.p.s. Whenever high gains are employed such that small voltages produce full-scale patterns on an oscillograph, it is essential that constant voltage power be supplied, especially to the early stages of amplification. Accordingly, each Pre-Amplifier includes a constant voltage power supply which provides a constant d-c. potential, irrespective of either sudden or gradual changes of a-c. line voltage input. Maker recommends "Type-AP2XB" angular sweep when oscillograph and pre-amplifier are used for engine studies.—*Rowe Radio Research Lab. Co., 4201 Irving Park Blvd., Chicago, Ill.*

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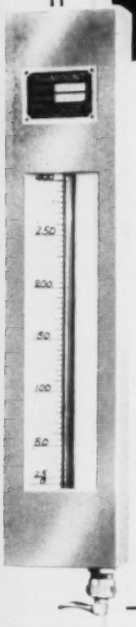

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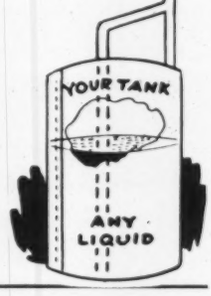
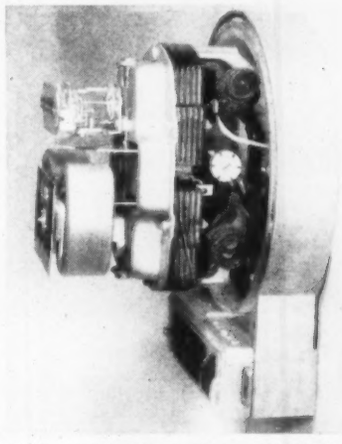


TRIMOUNT INSTRUMENT CO.
37 W. Van Buren St. Chicago, Ill.

Industrial Switchboard Watthour Meters

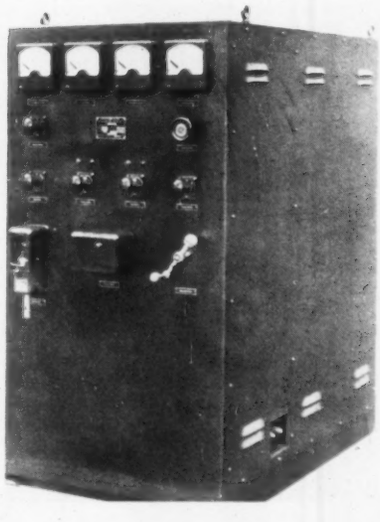
A new and complete line of switchboard watthour meters is announced. These "Type CB" meters are available with rear connection stud terminals for use with instrument transformers or self-contained up to 50 amperes; for either projection or semi-flush mounting. Meters up to 15 amperes are for



semi-flush mounting, except "CB-32" and "CB-38" which can be changed to plug-in type by replacing the screws or stud terminals with blade terminals. All meters are complete with rectangular cases to match maker's standard rectangular relay cases. The plug-in features, said to provide a new convenience in switchboard meters, are provided with automatic circuit closing devices which operate when the meter is removed from the board. This eliminates service interruptions during inspection and maintenance. This same device serves also to short circuit current transformer secondaries. Illustration shows a two-element "Type CB" switchboard watthour meter for semi-flush mounting.—*Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.*

D-c. Cable-fault Reduction and Localization Set

A complete line of metal-enclosed D-c. Cable-fault Reduction and Localization Sets is announced. This equipment, for use by utilities in reducing and locating faults on power-cable systems, operates on the "direct" method. While this method necessitates traversing the cable and observing indications at manholes, it is positive and, for average faults, it is said to require less time than other popular methods of fault location. Complete set consists of a Thyratron rectifier, control, motor-driven inter-



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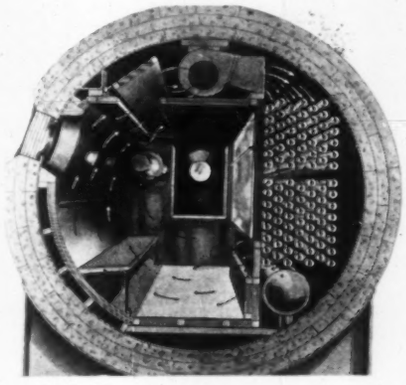
and current-limiting reactor, com- enclosed in a metal housing, and a le field set for taking readings along able. The set first reduces the resist- of the fault to a satisfactory value then transmits a tracer current which be easily recognized by traversing the with the portable field set. This equip- can be used up to its maximum- voltage for d-c. high-potential tests ible systems and other apparatus. It ailable in eight different ratings up to volts and up to 20 amperes.—*Gen- Electric Co., Schenectady, N. Y.*

Room-size "Strato-Chamber" for Personnel, Large Parts, etc.

In new "Strato-Chamber," for physiologi- and product research and testing, a main chamber approx. 18 ft. long is entered through a "lock" approx. 4 ft. long. Inside main chamber, an insulated high-altitude chamber is constructed with space on one side for refrigerant coils and a plenum space between high-altitude chamber and main chamber for circulation of air (see cross-sectional view). By means of dampers, altitude chamber can be completely isolated from flow of air from the refrigerated space. Refrigeration is supplied by a two-stage Freon-12 system operating at −85°F. suction temperature; evaporator coils are fed from a Freon-12 liquid circulating pump, which



insures continually efficient coil operation without danger of liquid slugs to compressor. *Operation:* (1) Altitude test chamber is closed off from refrigerated space and the refrigerating equipment operated long enough to lower temperature of coils, shell, insulation, etc.; fans are not in use and air flows by gravity down through coils and around test chamber through circular space back to coils. Coils and shell are cooled to a temperature of −100°F. or lower. (2) After this preliminary cooling period, test chamber is heated to normal atmospheric temperature by means of fan heaters, and is then ready for the test period. (3) After test subjects have been put into the test chamber, fans are started and the dampers admitting cold air to test chamber are opened. A sufficient reservoir of refrigeration has been built up, by lowering the temperature of coils, refrigerant, shell, etc., to −100°F. to reduce the temperature within the test chamber to −70°F. in 12 minutes. (4) Concurrently, vacuum equipment reduces pressure in both test chamber and "lock" or entry port from normal sea-level pressure to stratospheric air pressure (2.75 lbs./in.² absolute.) This pressure is maintained with a fresh air "bleed" into the chamber of approx. 10 ft.³/min. This fresh air is necessary for ventilation, since oxygen masks are in constant use inside and oxygen concentration is high. Vacuum pumping equipment is lubricated and sealed to handle air of high oxygen concentration without danger of explosion. (5) Entry port or "lock" is used as a decompression room, providing access to test chamber from outside without disturbing conditions within.—*York Ice Machinery Corp., York, Pa.*

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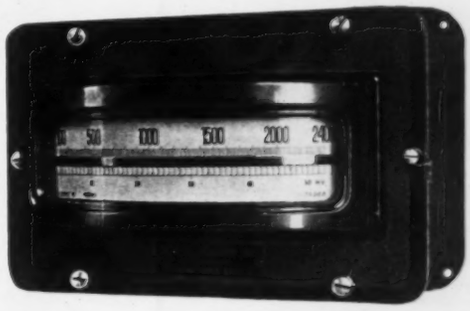

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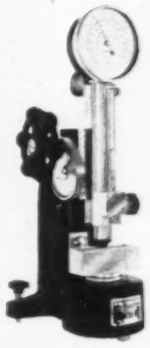

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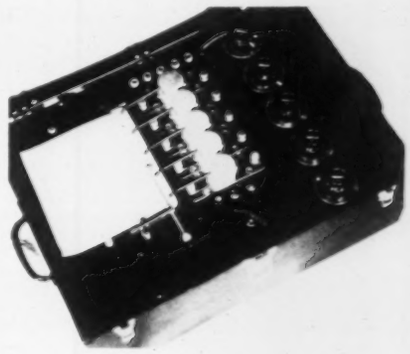

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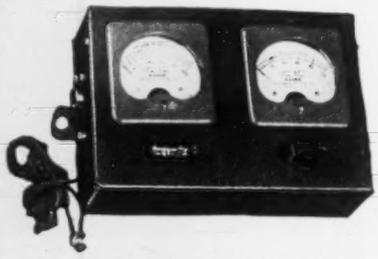

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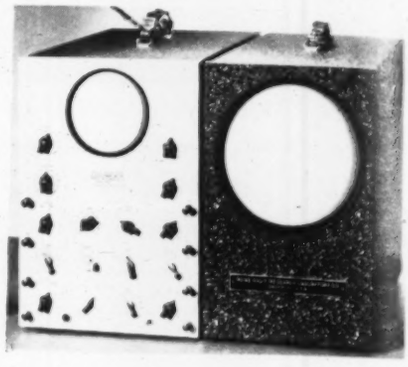
New direct current motor-operated valves are available in valve sizes from ½" to 2". They have been designed for two-position (on-off) control of steam, water, or gas. The majority of types available may be used for oil or brine. The valves are suitable for use on heating and cooling coils, bottle washers, plating tanks, humidifiers, hot water storage tanks, boiler feed water control, etc. They are operated by heavy-duty "Type JYBA" operator for marine and industrial application. Powered by a ball bearing Eicor series wound direct-current motor. All motor parts are corrosion proof. Gear reduction of precision hobbed, heat treated gears. Beryllium copper limit switches. Fine silver contacts. Timing characteristic of operator is 35 secs. per stroke. Operators are available for 24-volt, 115-volt or 230-volt d-c. supply. These motor-operated valves are controlled from a single-pole double-throw switch or its equivalent such as a thermostat, pressure switch, float switch, or relay. The unit may be mounted in any position. Maximum pressures of ½" size are 100 or 150 lbs./in.²; of largest (2") size, 70 or 150 lbs./in.2.—*Barber-Colman Co., Rockford, Ill.*

General-purpose 5"-9" Oscillograph

New "Type D5RR9" Combination Five-inch — Nine-inch Oscillograph is a general-purpose unit employing all of the features of the DuMont "Type 175-A" Oscillograph, but also permits the use of either a 5" or 9" cathode-ray tube. The oscillograph proper is a modified DuMont Type 175-A (see *Instruments*, Dec. 1939, page 316). Its modifications do not affect its characteristics in any way but permit its use with the Rowe Radio Nine-inch Adaptor and other auxiliary Rowe Radio apparatus. For most applications, particularly in connection with



fuel study work and engine development projects, the units will be supplied with a 5" blue tube and 9" green tube. The short-persistence or "fast" blue tube in the 5" size is best suited for photographic work. The 9" tube with medium persistence green screen is better suited for visual studies. This combination oscillograph is recommended for use with maker's pre-amplifier (described elsewhere in this issue) and angular sweep (see *Instruments*, Dec. 1941, page 388).—*Rowe Radio Research Lab. Co., 4201 Irving Park Blvd., Chicago, Ill.*

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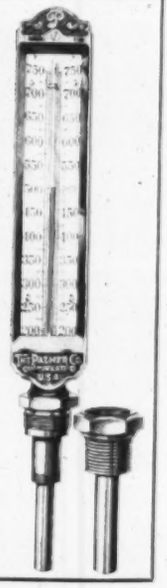

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Mass Training of Instrument Mechanics

(Continued from page 428)

task of providing the necessary equipment and space for the conduct of the enlarged school, the task of selecting and training a staff of 42 instructors has been even greater.

The Chicago School of Aircraft Instruments was fortunate in having a group of civilian graduates and another group of civilians in training who were unusually competent. From these groups have come most of the present instructors in both the Army Air Force School and the Civilian School. These men have been put through intensive training programs at the Chicago School of Aircraft Instruments, and as many as possible have been sent out for special training by the manufacturers of aircraft instruments. Only because these young men were vitally eager to do the job and do it right, and because they were willing to spend all of their waking hours learning to be instructors, has it been possible to have the staff that is now available.

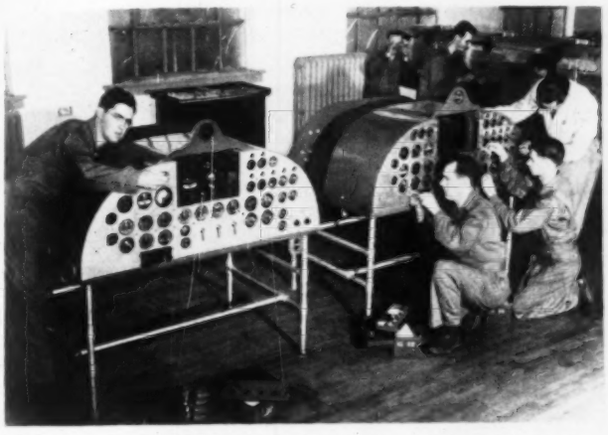


Fig. 5. To equip its expanded Instrument school, engineers of the Chicago School of Aircraft Instruments had to design and make many pieces of special equipment such as these mock-ups of Douglas DC-3 instrument panels, on which students learn instrument installation, wiring and plumbing.

In the Chicago School of Aircraft Instruments, each student class is made up of fifteen men, and there is an instructor for each class at all times.

In the Civilian School, the student begins his training by spending four weeks in the School's primary shop, learning to operate bench lathes and jeweler's lathes, to use hand tools and test equipment, and developing the skills and techniques that all instrument men must have. Students who

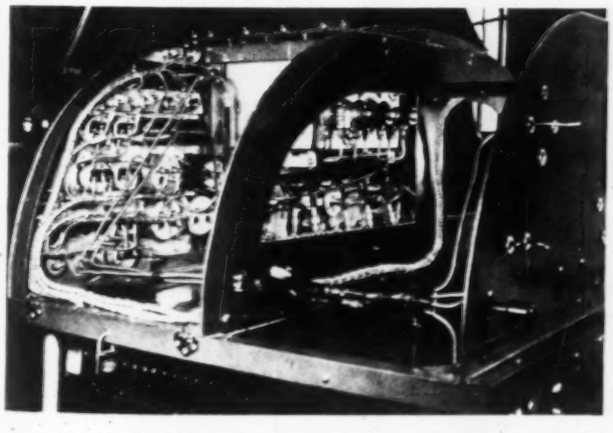
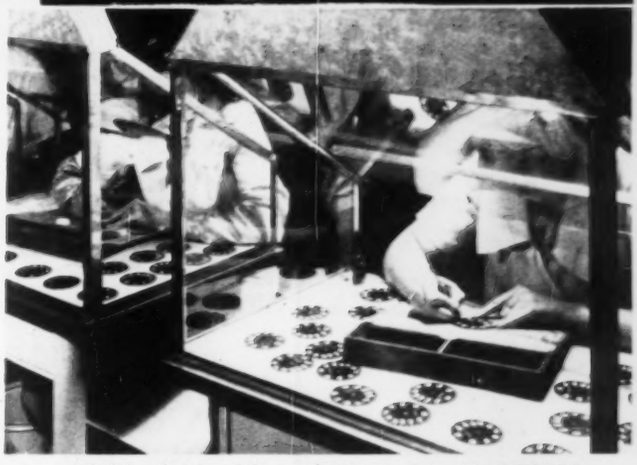


Fig. 6. Close-up of the interior of one of the instrument panels shown in Fig. 5. Working in groups of three, students completely remove all instruments and connecting lines and reinstall them as shown in this picture.

under cover of Darkness...



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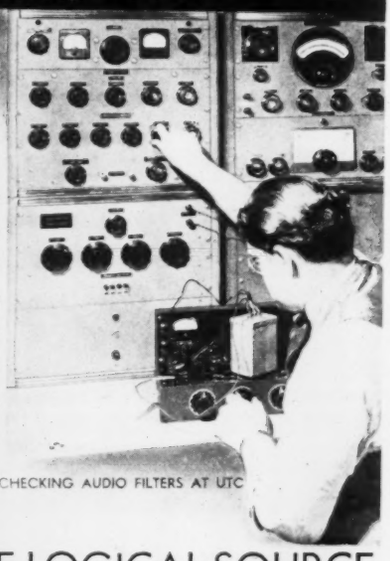

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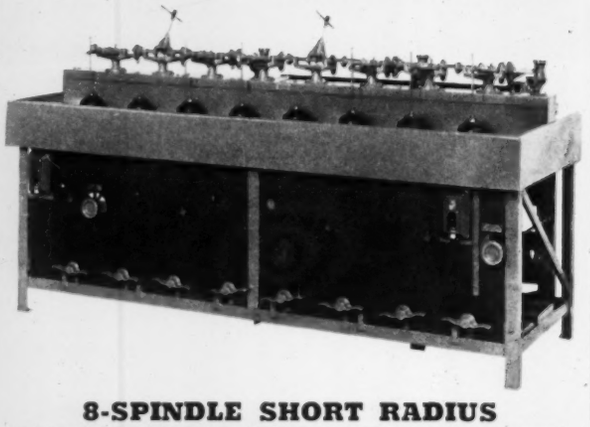

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cannot satisfactorily do the required work in the primary shop are not permitted to go on into instrument training.

From the primary shop, the student goes into two weeks of intensive training on general instruments of the mechanical and pressure type, and then into six weeks on electrical instruments, and six weeks on gyroscopic instruments.

Students in the Army Air Forces School are given what is fundamentally the same type of training except that they are made into specialists. One group specializes in mechanical instruments, another on electrical instruments, and the third on gyroscopic instruments.

Today, the Chicago School of Aircraft Instruments is probably the largest such school in the world. On January 15, it occupied one small room on the third floor of the American Airlines Hangar on Chicago's Municipal Airport. Today it has the use of more than 60,000 square feet of floor space formerly occupied by its parent organization, the Industrial Training Institute. On the campus of the Chicago School of Aircraft Instruments today, are two Army barracks, a cafeteria, the students' clubroom, and many other facilities. All of this, of course, has been made possible because the Chicago School of Aircraft Instruments happened to be a subsidiary of one of the largest industrial training schools in the country, and could draw upon all of the resources of the parent school as well as its twenty-five years of educational background and its experience of training almost 400,000 men for other industrial fields.

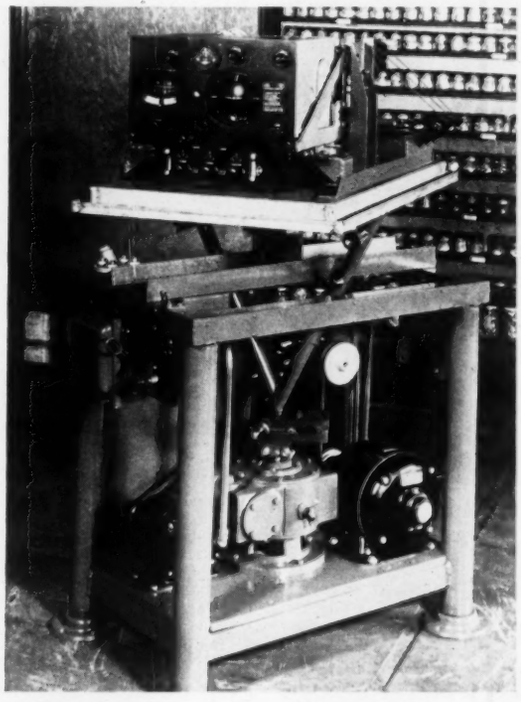

Fig. 7. Essential to the understanding and repair of Automatic Pilots are "Scorsby" test units. Because no such units could be purchased, engineers at C.S.A.I. had to make their own from the ground up, with the co-operation of the Sperry Gyroscope Company. This particular unit is used in the Civilian School. Similar units were made for the Air Forces School.

Between the Civilian School and the Army Air Forces School, the Chicago School of Aircraft Instruments is today graduating more than a hundred men a month—every one of them completely trained and ready to take his place in making or maintaining the instruments needed in our military and civilian aircraft.

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Hairspring Straightening Simplified

By ELSWORTH KEITH, Jr.

MOST apprentice instrument repairmen experience great difficulty in the repair of bent or damaged hairsprings. A great deal of this trouble is often due to the difficulty in locating the damaged portion of the spring. This problem may be greatly simplified by placing the

Straightening a hairspring on a piece of frosted glass. Note the absence of confusing shadows even in the photograph.

spring on an object which will eliminate any shadows which might be cast by the hairspring when it is placed under the working light.

A piece of ground or frosted glass about 3" × 3" placed on a piece of white paper under the light will provide this shadowless background. Any piece of glass may be ground by rubbing it on a lapping plate with a medium cut lapping compound.

This method of working on a hairspring will often obviate the need of using a loupe; and will always reduce eyestrain.

Pivot Repairing

By ELSWORTH KEITH, Jr.

TODAY, when so many of the small and intricate parts in the modern aircraft instrument are unobtainable from the manufacturer because of continually increasing demands on production facilities, it becomes extremely important that the instrument technician be able to repair as many of these parts as possible.

The overhaul of many instruments is delayed overlong because of broken handstaffs, pivots, and the like. The greatest difficulty experienced in the average shop, insofar as such repair is concerned, is the drilling of the extremely hard materials of which the parts are made. Such drilling is, of course, for the purpose of providing a hole into which may be pressed the new pivot or handstaff. This repair would make the part wholly useful again.

The difficulty of this drilling job can be greatly reduced by proper annealing of the broken part. This may be done

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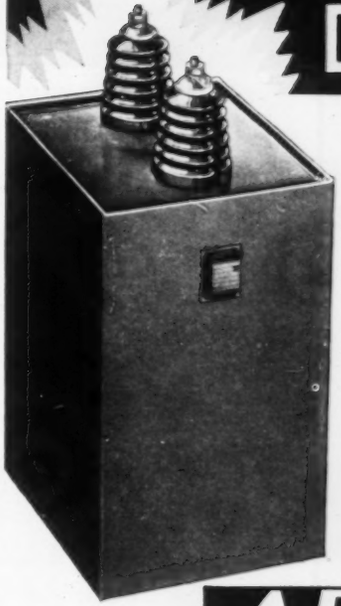

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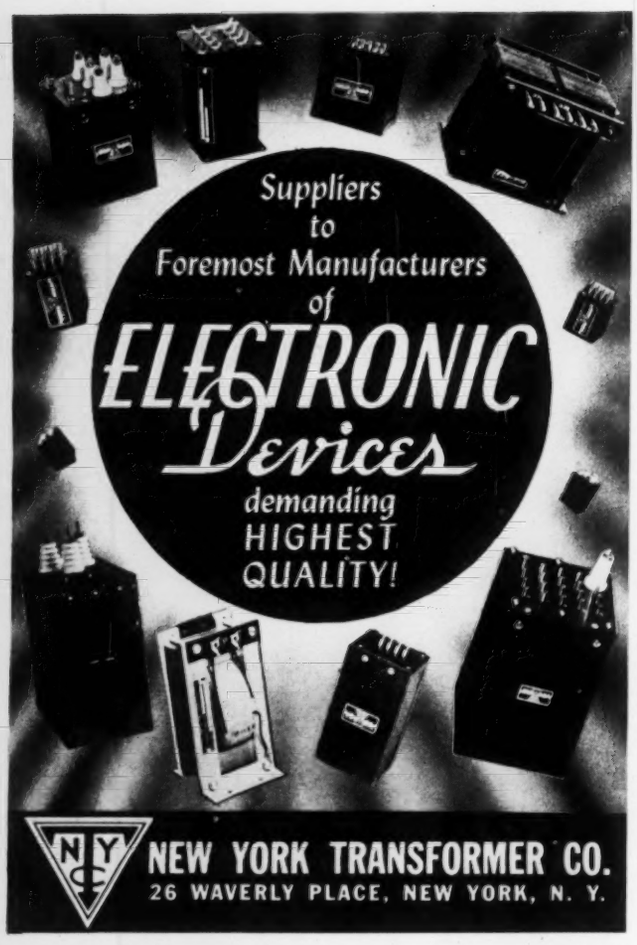

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by placing the part in the middle of a short ¼" pipe nipple which is then filled with fine iron filings and capped at both ends. The whole unit is then heated to a bright cherry red with a blowtorch or suitable substitute, and then buried in a can of lime. (This keeps the pipe from cooling too rapidly.) Any steel part which has been treated in this manner may be easily drilled with the ordinary pivot drill or small twist drill.

The replacement pivot or handstaff should be made to be a press fit in the drilled hole. After the finished part has been assembled, the entire unit may be re-hardened by repeating the heating process in the pipe nipple, and then quenching the entire unit in cool oil.

Any part treated in this manner will retain its original polished finish, and will be a most satisfactory temporary repair, often lasting as long in service as a new part.

Thermometric Lag Determination

(Continued from page 403)

perature difference to one-half its initial value will be $1.84 \times 95 = 175$ sec.

By this type of analysis the lag characteristics of different elements under different operating conditions can be readily compared. Whether the time for $\phi = 0.5$ or some other value is selected as the criterion is immaterial provided the comparisons are made for the same value of ϕ.

Determination of Time for $\phi = 0.5$
$R = 5$ mm. $A = 0.5$ (Fig. 4)

EXPERIMENTAL DETERMINATION

Medium	Time for $\phi = 0.5$	h	Ak
Still water	95 sec.	980	490
Still air	550 sec.	12.7	6.35

Ratio $550/95 = 5.8$

FROM CURVES OF FIG. 3

k	h_c water = 490	h_c air = 6.75	Ratio of Times Air/Water
0.1	680 sec.	2800 sec.	4.1
0.2	380	2250	5.9
0.3	250	2200	8.8

Conductivity = 0.2

TIME for $\phi = 0.5$ in Air at 10 m./s.
h for Air at 10 m./s. = 90 (See Table II)
$h_c = 0.5 \times 90 = 45$
Time corresponding to $h = 45$ (From Fig. 3) 700 sec.
Time ratio = 700/380 = 1.84
Time for $\phi = 0.5$ in air at 10 m./s. = $1.84 \times 95 = 175$ sec.

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IN use at the Westinghouse Lighting Division laboratories in Cleveland is the first photometer for fixtures using fluorescent lamps. It can measure light output and distribution of units as large as 10 feet in diameter. It consists of a heavy rotating base which supports an adjustable arm. The luminaire is securely attached to this arm and can be

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Figure 1

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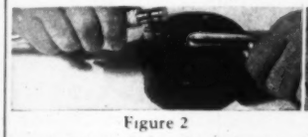
Figure 2

Figure 3

Figure 2 shows the unique method of attaching rigid or flexible connecting arm. Figure 3 illustrates easy attaching of thermocouples to arm yoke.

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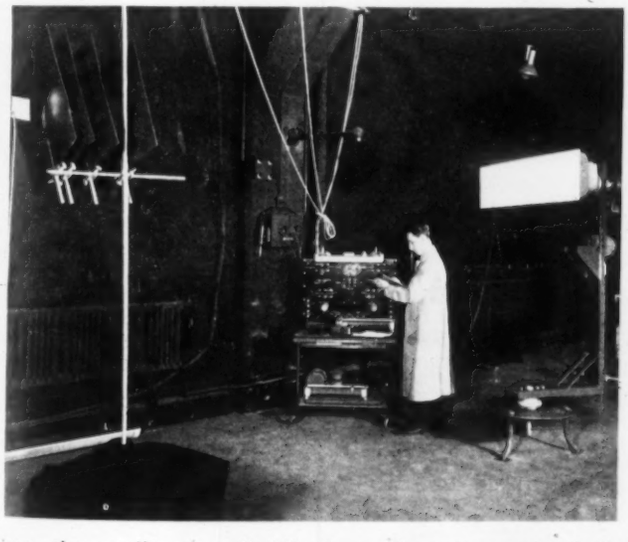
rotated to any position desired for reading. Measurements are made by means of a photocell mounted at the same height as the luminaire at a given distance away. The photocell output, directly proportionate to the amount of light falling on the cell, is measured with the luminaire rotated to various angles about the cell. From these read-



ings the candlepower distribution and performance of the luminaire can be computed. Brightness tests are made with a Macbeth illuminator. Efficiency of the luminaire is computed from candlepower values, using the proper zonal constants:

Design engineers find the photometer apparatus useful during the development of a lighting unit, as well as for making commercial tests.

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